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Plants, Metallic Pollution and Environment in Katanga (DR Congo): A Human and Scientific Adventure*

by

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KEYWORDS. — Biological Diversity; Ecological Restoration; Copper; Metallophyte; Soil.

SUMMARY. — The authors report here the history of a cooperation development project between the Faculty of Agronomy of the University of Lubumbashi (DR Congo), the *Université Libre de Bruxelles* and *Gembloux Agro-Bio Tech – Université de Liège*. The project addressed the issue of ecological restoration of soil contaminated with heavy metals by metallurgical industry. It comprised the organization of specialized Master courses and the development of applied scientific research. It owed its success to transparency in the selection of applicants, the continued motivation of students and team building during practical field exercises. Synergies with young researchers in the North also reinforced the project. Four students obtained a PhD during the project and twenty-two obtained a Master. Most of them are now active in research or expertise related to environmental ecology.

MOTS-CLES. — Biodiversité; Restauration écologique; Cuivre; Métallophyte; Sol.

RESUME. — Les auteurs relatent le déroulement d'un projet de coopération au développement entre la faculté d'agronomie de l'Université de Lubumbashi, l'Université

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Libre de Bruxelles et Gembloux Agro-Bio Tech – Université de Liège. Le projet était centré sur la restauration écologique des sols contaminés en métaux lourds par l'industrie minière au Katanga (RD Congo). Il comprenait un volet de formation, structuré sur l'organisation d'un diplôme de Master spécialisé, et un volet de recherche-développement. L'article insiste surtout sur les aspects humains du projet. Le projet doit largement son succès aux procédures de sélection transparentes des étudiants, à sa prise en charge locale par un groupe d'étudiants très motivés, au renforcement de l'esprit de groupe par des travaux pratiques de terrain et à l'établissement de collaborations de recherche avec de jeunes chercheurs du Nord. Quatre thèses de doctorat et vingt-deux mémoires de Master ont été soutenus pendant le projet; la plupart des lauréats sont aujourd'hui engagés dans des travaux de recherche ou d'expertise dans le domaine de l'environnement.

TREFWOORDEN. — Biodiversiteit; Ecologisch herstel; Koper; Metalofyt; Bodem.

SAMENVATTING. — De auteurs brengen verslag uit over een ontwikkelingsproject tussen de landbouwfaculteit van de Universiteit van Lubumbashi, de *Université Libre de Bruxelles* en *Gembloux Agro-Bio Tech – Université de Liège*. Het project was gericht op het ecologisch herstel van bodems vervuild door zware metalen ten gevolge van de mijnbouwindustrie in Katanga. Het bevatte een luik onderwijs, onder de vorm van een masteropleiding naast een luik onderzoek en ontwikkeling. Het artikel legt de nadruk op de menselijke aspecten van het project. Het welslagen ervan berustte hoofdzakelijk op transparante selectieprocedures, een projectopvolging ter plaatse door een groep zeer gemotiveerde studenten, de versterking van de groepssfeer door middel van praktische oefeningen op het terrein en door de ontwikkeling van onderzoekssamenwerkingsverbanden met jonge vorsers uit het Noorden. Vier doctoraatsproefschriften en tweeëntwintig masterproefschriften werden verdedigd in het kader van het project; de meerderheid van de laureaten zijn thans aangesteld in onderzoekswerkprojecten of expertiseopdrachten met betrekking tot milieubeheer.

Introduction

The Katangan Copperbelt deposits contain some of the world's largest known copper-cobalt resources. These mineral resources have since long been exploited by man, initially by artisanal mining and, starting in the early twentieth century, on an industrial scale.

All steps of the mineral non-ferrous industry potentially contaminate the environment. Smelting of metalliferous ores, in particular, can spread metalliferous smokes over large areas. Atmospheric fallout of heavy metals and acidic compounds has occurred in various places worldwide around metal processing facilities. In Lubumbashi, emissions from the copper smelter of the *Union minière*, then *Gécamines*, has contaminated landscapes situated downwind over a huge area. The initially-present forest vegetation has been replaced by a steppe-like savanna and bare soils. Erosion by wind and water is consequently intense. Copper concentrations observed in the topsoil are extremely high, often even exceeding 10,000 mg kg^{-1} a kilometre away from the chimney (VRANKEN *et al.* 2013).

The *Code minier* (Law no. 4-2005 of April 11) compels mining companies to perform an environmental impact assessment when starting up a new project, and to restore the industrial or extraction site after completion of the project. Impact assessment studies and site restoration require specific skills and a particular interdisciplinary scientific expertise, at the crossroads of agronomy, plant sciences, soil sciences and environmental ecology.

Metalliferous bedrock outcrops in Katanga appear as "copper hills". They host a unique and species-rich plant cover, with over six hundred and fifty species, thirty-two of which are identified as "copper endemics", *i.e.* species that only occur on copper-rich Katangan soils (FAUCON *et al.* 2010). These species have evolved physiological and biological adaptations in order to survive extremely high concentrations of Co and Cu in the soil (BAKER *et al.* 1983, CHIPENG *et al.* 2010). Such species consequently represent important biological resources for environmental technologies aiming at restoring vegetations on metal contaminated soils worldwide. The implementation of the aforementioned mine laws offers new employment opportunities for scientists specialized in environmental issues.

This context has prompted the Faculty of Agronomy of the University of Lubumbashi (UNILU), in collaboration with the *Université Libre de Bruxelles* (ULB) and the *Gembloux Agro-Bio Tech – Université de Liège* (ULg-Gembloux) to launch a project focusing on the environmental impact of metallic pollution and its remediation by means of metal-tolerant plants. At the beginning of the project, the Faculty of Agronomy of UNILU had only one full-time professor, and its research activities were mostly focused on soil mapping.

Here we briefly trace the history of the project. This short account is not primarily focused on the scientific results of the project. Rather, we pay attention to its human dimension.

The project «*Appui à la création d'un troisième cycle en biologie végétale et environnement à l'Université de Lubumbashi (R.D. Congo) et approche multiscalaire de la remédiation des sols contaminés (REMEDLU)*»

The project was funded by the CIUF, the *Commission universitaire pour le Développement* (CUD-CIUF, now called ARES-CCD) for five years. The project consortium was composed of the University of Lubumbashi (DR Congo), the *Université Libre de Bruxelles* and the *Université de Liège/Gembloux Agro-Bio Tech*. Six professors from the North were involved, and for five of them the project marked their first experience in development cooperation in the tropics.

The first objective of the project was to increase the Faculty of Agronomy's expertise in environmental ecology of metallic pollutions and its capacity to establish itself as a major player in the assessment and restoration of the ecological impact of mineral industry.

The second objective was to conduct innovative research initiatives on the impacts of metallic pollution in ecosystems and on the remediation of those impacts using original plant systems based upon native biodiversity resources.

To address these objectives, the project included a training programme aimed at capacity building of young agronomists in the environmental ecology of metallic pollution, and the development of applied ecological research.

Activities of the project were organized on four sites:

— A classroom entirely dedicated to the project was installed and fully equipped;
— An experimental botanical garden was created at walking distance from the classroom;
— An experimental study site located in the area polluted by fallout from the chimney of the copper smelter of Lubumbashi (Penga Penga) was used for teaching and research;
— "Copper hills", *i.e.* natural sites on metalliferous outcrops, with a specific biodiversity adapted to heavy metal stress, were used for teaching and research.

The Master in Agronomy, Specialized in Plant Biology and Environment

A specialized Master in Plant Biology and Environment was set up. The training was organized as a one hundred and twenty Credit Specialized Master course, which comprised a personal research project. The Master was organized twice consecutively (tabs. 1, 2).

Table 1
Milestones in the project

August 2005	Launch of the project; selection of the first group of students
December 2005	Creation of the botanical garden
September 2006	Selection of the four PhD students
October 2007	Master thesis defence of the first graduates
	Selection of the second group of students
October 2009	Master thesis defence of the second group
November 2010	Public thesis defence of the four PhD students
	Closing ceremony of the project

Table 2
Programme of the *Master complémentaire en Agronomie, spécialité Biologie végétale et environnement* (courses given in French. One credit is 15 h.)

First year (60 credits)
• Eléments d'écologie générale [General Ecology]. Prof. P. Meerts (ULB) (3 credits) • Pédologie [Soil Science]. Prof. G. Colinet (ULg-Gembloux Agro-Bio Tech) & M. Ngongo (UNILU) (3 credits) • Eléments de physiologie végétale [Plant Physiology]. Prof. N. Verbruggen (ULB) (3 credits) • Phytogéographie [Phytogeography]. Prof. L. Ndjele (UNIKIS-Kisangani) & G. Mahy (Ulg-Gembloux Agro-Bio Tech) (3 credits) • Méthodologie de la recherche [Methodology of scientific research]. Prof. M. Ngongo (UNILU) (3 credits) • Statistique et traitement des données [Statistics]. Prof. Kiatoko (UNIKIN-Kinshasa) (3 credits) • Floristique et Systématique végétale appliquées au Haut-Katanga [Flora and vegetation of Upper Katanga]. Prof. J. Lejoly (ULB) (3 credits) • Systèmes d'Information Géographique: principes et applications [Geographic Information Systems]. Prof. J. Bogaert (ULB) (3 credits) • Séminaires [Seminars] (6 credits) • Recherches dans le cadre du mémoire de DEA [Personal project] (30 credits)
Second Year (60 credits)
• Gestion de la biodiversité [Biodiversity management]. Prof. G. Mahy (ULg-Gembloux Agro-Bio Tech) (3 credits) • Relations plantes-sols et phytoremédiation [Soil-Plant relationships and phytoremediation]. Prof. N. Verbruggen & P. Meerts (ULB) (3 credits) • Pédologie approfondie et pollutions [Advanced soil science and soil pollution]. Prof. M. Ngongo (UNILU) & G. Colinet (ULg-Gembloux Agro-Bio Tech) (3 credits) • Informatique [Computing]. Prof. Bavuesa (UNILU) (3 credits) • Communautés végétales des sols métallifères [Plant communities on metal-rich soil]. Prof. J. Lejoly (ULB) (3 credits) • Ecologie du paysage [Landscape ecology]. Prof. J. Bogaert (ULB) (3 credits) • Séminaires [Seminars] (6 credits) • Stages professionnels [Internship] (6 credits) • Recherches dans le cadre du mémoire [Personal project] (30 credits)

The programme aimed at promoting an interdisciplinary approach, with a broad coverage of environmental issues related to metallic pollution, ranging from the physiology of metal tolerance over soil pollution to landscape ecology. However, an emphasis was deliberately put on plant systems, as promising tools to mitigate soil metallic contamination.

In the second year of the Master programme, each student had to choose the subject of his/her Master thesis. The Master thesis was a personal research project, supervised by one of the six European professors involved in the project.

Some Keys to Success

Transparency in the Selection of Applicants

A call for applications was broadly spread at the university. Applicants were graduating preferably in agronomy. Many more applications (thirty to forty) were received than places available. The number of students enrolled was limited to fifteen, in order to ensure effective pedagogic support and because the budget of the project was limited. Applicants were selected on the basis of an entrance exam. This included a written exam, a motivation letter, a CV, and an interview. Students very much appreciated that the selection was based on objective, transparent criteria and this ensured a positive atmosphere in the group from the beginning.

Students as Full Partners of the Project

From the start, students were considered as full partners of the project. Great efforts were made to convince students to take ownership of the project. Therefore, they received specific responsibilities in the project (library, classroom maintenance, external relationships, field trip organization and so forth).

At the end of the first year and based on the marks obtained in the exams, four PhD candidates were selected. They played a prominent role in the second phase of the project. In particular, they organized the practical exercises associated to teaching units and co-supervised the Master theses of the second group of applicants. They also took care of the local management of the project.

Team Building in the Field

No doubt the field trips were highlights of the training. Most importantly, they played a key role in team building. Students took care of most of the logistics, including obtaining authorizations from mining companies and local authorities. Field trips focused on biodiversity resources, which can be used to implement ecological restoration. For most students, realizing that native plant species can be useful, beyond providing food or medication, came as a surprise. Realizing that some of those species are endemic to Katanga and therefore represent major targets of biological conservation also came as a surprise.

Infrastructures

The project included the installation of three infrastructures: a classroom, a laboratory and a botanical garden. The objectives of the botanical garden were threefold. First, it was used for teaching. A collection of "metallophytes",

i.e. plant species adapted to metallic pollution, was transplanted from the field. Practical courses were organized and students were trained to identify plant species and their value as bioindicator. Second, the garden was used as a research instrument, with experimental plots. The first trials of phytoremediation were made in 2006. Third, the garden was used as a "showcase" and a communication tool to promote the project for stakeholders, mining companies and all possible partners. The collections of metallophytes have proven difficult to maintain in the long term and nowadays subsist only in part, but the experimental plots are still used to conduct scientific research.

Research

The applied scientific research of the project was conducted mostly by the four PhD students selected in September 2006. They addressed complementary aspects of environmental ecology of heavy metal pollution in Katanga. Each of them had the opportunity to stay in Belgium for several months in their respective promoter's lab.

Mylor Ngoy Shutcha investigated the possibility of using native grasses to restore plant cover on the most copper-contaminated soils. His work was mostly experimental. It included the first successful field trial of phytostabilization of metal-polluted soil in tropical Africa, using the native grass species *Microchloa altera*. The plots are visible on Google Earth (11°40'34,49'S 27°27'06,97'E) (NGOY SHUTCHA *et al.* 2015).

François Munyemba Kankumbi specialized in landscape ecology. He used remote sensing imagery (satellite and aerial photography) to quantify and model landscape pattern dynamics caused by the impacts of metallic pollution and human action.

François Chipeng Kayemb investigated the mechanisms of metal tolerance in the "copper flower" (*Haumaniastrum katangense*), an emblematic species of the copper-contaminated soils in Katanga.

Michel Mpundu Mubemba assessed soil contamination at the study site and investigated impacts of soil contamination on vegetable production and quality.

Synergies in Belgium

Ten Belgian undergraduate students were indirectly involved in the project, having stayed in Katanga for their Master thesis project. One student from the North obtained a fellowship funded by the FRIA (FNRS, Belgium) to prepare a PhD thesis related to the topic of the project. He significantly reinforced collaboration between the North and the South.

Capacity Building

The project has reached its goal to train young scientists and prepare them to serve as experts in environmental impact studies. The Faculty of Agronomy of the University of Lubumbashi has gained reputation for its expertise in applied environmental ecology. After the end of the project, the Master was funded for two years by a private sponsor and has since then evolved into a Master in Biodiversity Management. Eight trainees of the project have now obtained a PhD and are occupied as full-time professors in Congolese universities or high schools, eight others have obtained a fellowship to prepare a PhD thesis in Belgium, Canada or DR Congo. Two are employed as environmental experts in mining companies. The Faculty of Agronomy now counts more than ten full-time academics, and has greatly diversified its research activities. Significantly, one of the PhD students of the project has now become the Dean of the Faculty.

Conclusions

The results of the project show that ecological and agronomic solutions for mitigating impacts of mining activities in Katanga do exist. However, Katanga is facing manifold socio-economic challenges. In that context, challenges related to environmental issues might not be viewed as a priority. Law enforcement (*Code minier*) critically depends on a strong political will. Further projects are needed to continue ongoing research and to open new research fields. Partnerships with mining companies are dependent on the health of the mining sector, itself following the price of non-ferrous metals on international markets. Political, economic and academic stability are necessary conditions for a sustainable development of the Katangan ecosystems and for the follow-up of their health.

Capacity building is one of the missions of universities in developed countries. However, it is still not sufficiently valued in the academic career. The experience gained during this project shows that it can yield peer-reviewed publications and strengthen research teams both in the North and in the South.

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The following students obtained their PhD at the end of the project: Ngoy Shutcha Mylor (UNILU), Mpundu Mubemba Michel (UNILU), Chipeng Kayemb François, Munyemba Kankumbi François (UNILU), Amisi Mwana Yamba (UNILU), Faucon Michel-Pierre (ULB).

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