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Early stages of natural revegetation of metalliferous mine workings in South Central Africa: a preliminary survey

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The various types of mining sites resulting from human activities in the Katangan Copper Bow and the Zambian Copperbelt are described and a typology is presented whereby ten different situations are recognized. Performance as well as distribution of the diverse plant species observed on these sites is considered. A set of nine ecological conditions is suggested, based both upon the heavy metal content of soil as well as its state of hydration. One taxon is identified as an indicator of each condition recognized. The information presented here is a preliminary requirement for planning the revegetation of metalliferous sites within the area.
Keywords. Metalliferous sites, pollution, heavy metals, revegetation, phytogeochemistry, South Central Africa.

Premiers stades de la verdurisation naturelle des exploitations minières métallifères d'Afrique centro-australe : approche préliminaire. Les auteurs répertorient, pour l'Arc cuprifère katangais et la Copperbelt zambienne, les catégories de sites miniers résultant de l'activité anthropique. Une typologie est établie, 10 situations différentes y sont distinguées. Ils envisagent ensuite les comportements et distributions des différentes espèces observées dans ces sites. Un ensemble de 9 conditions écologiques est proposé sur base de la teneur en métaux lourds du sol ainsi que de son hydratation. Un taxon est identifié pour chaque condition reconnue. Cette information constitue une étape préalable à l'étude de la verdurisation des sites métallifères de la dition.
Mots-clés. : Sites métallifères, pollution, métaux lourds, verdurisation, phytogéochimie, Afrique centro-australe.

1. INTRODUCTION

Heavy metal ore bodies occur throughout the Katangan Copper Bow and the Zambian Copperbelt (**Figure 1**) on about 70 sites. They are expressed in more than 120 metalliferous deviating features, in the form of grasslands, mostly developed on hills emerging from the medium middle plateau covered with miombo woodland. These grasslands support several unique plant community types, including a *Uapaca robynsii* shrubby savanna belt, a *Loudetia simplex – Monocymbium ceresiiforme* steppe savanna, a *Xerophyta* spp. stone-packed steppe and other herbaceous swards (Malaisse *et al.*, 1994).

Extractive heavy metal activity started a long time ago in South Central Africa where copper was already an important commodity of trade. Copper metallurgy has been reported as already existing during the 14th century in Katanga (De Plaen *et al.*, 1982). Several sites of exploitation of copper minerals and of furnaces traditionally used in pre-colonial days for the production of small copper crosses were respectively located from excavations on rocky slopes and by the remains of old furnaces but even more effectively by the presence of carpets of *Haumaniastrum katangense* (S. Moore) P. A. Duvigneaud & Plancke. The presence of this annual metallophyte away from copper outcrops on man-made substrates which are slightly or heavily mineralized has led to interesting archaeological discoveries and is an original approach to phytoarchaeology.

Pre-colonial metallurgy resulted in the production of copper croisettes which were used as money. The significance of croisettes has been commented upon elsewhere; their sizes vary considerably ranging in weight from a few grams up to 36 kg (De Plaen *et al.*, 1982). With the development of the heavy metal industry during the beginning of the colonial period, some severe pollution events occurred involving air, soil and water contamination.

Water contamination has been observed in several water courses below the site of metal processing plants. This is the case for Likasi as well as in the vicinity of the Etoile Mine, near Lubumbashi. In some parts of the watercourse alluvial mineralized deposits can be found. This is for example the case for the

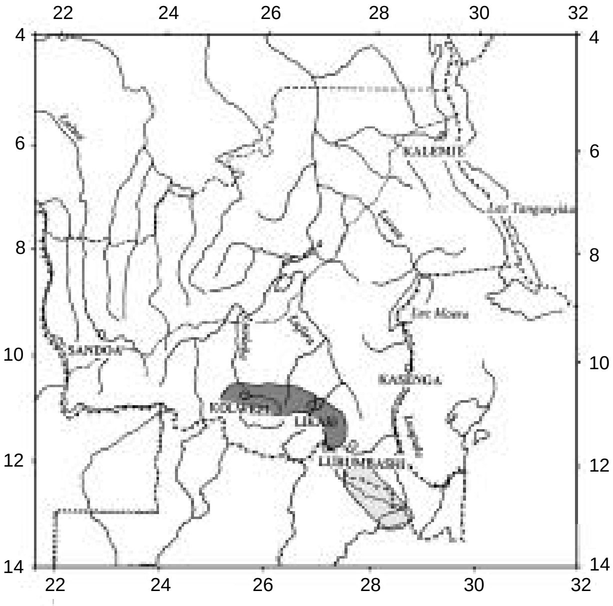


Figure 1. The Katangan Copper Bow (Democratic Republic of Congo) and the Copperbelt (Zambia). After François (1973) — *Arc cuprifère katangais (République Démocratique du Congo) et Copperbelt (Zambie)*.

Katangan Copper Bow — *Arc cuprifère katangais.*

Copperbelt

Katanga Province— *Province du Katanga*

North-western limit of the Upper Katanga phyto-geographical District—*Limite nord-ouest du district phytogéographique du Haut-Katanga.*

Buluo stream near to its junction with the Pande river. These deposits may be considered to some extent as analogous to the settling tanks for instance such as washed tailings at Kipushi or sites where malachite rocks were washed along streams near to the Ruashi stream close to the Étoile Mine.

In general, soil contamination is far the most important form of pollution as it persists even after the closure of the processing plant. Extractive mining activities have involved millions of m^3 of soil displacement, including large amounts of lightly mineralized soils, frequently considered as "sterile". These polluted areas cover at present several tens of km^2 and their recovery emphasizes several serious ecological problems. Moreover, sterile rocks have been used for the consolidation of tracks, leading to a new type of pollution through the spread of mineral deposits along roads and tracks.

This paper presents preliminary observations on the early stages of natural revegetation of metalliferous mine workings and provides a background knowledge for future reclamation efforts.

2. TYPES OF MINERAL WORKINGS AND ASSOCIATED POLLUTION

Figure 2 presents the main kinds of heavy metal mineral workings observed as well as anthropogenic heavy metal pollution processes. They are:

- Precolonial sites of metallurgy, observed
  - along streams
  - in miombo woodlands (**Photo 1**)
- Prospecting trenchs from early colonial times (**Photo 2**). These include:
  - the bottom of the trench
  - the bare vertical faces with shaded conditions,
  - the exposed, dry rocky skeletal fragmented rocks accumulated on the upper side of the trench (**Photo 3**)
- Open quarries (**Photo 4**)
- Heaps of overburden materials:
  - soils formerly overlying mineralization (**Photo 5**)
  - large blocks of rocks and pitheads (**Photo 6**)
- Railway tracks enriched with cupriferous rocks
- Alluvial mineralized deposits downstream processing plants polluted by waste waters (**Photo 7**)
- Soil-surfaced paths and trackways reinforced with "sterile rocks" and the adjacent affected areas (**Photo 8**)
- Sites of mineral separation and washing (**Photo 9**)
- Settling tanks where mineralized muds are discharged (**Photo 10**)
- Heavy metal enriched dusts deposited downwind of smelting works (**Photo 11**).

3. THE METALLOPHYTE FLORA OF MINE WORKINGS IN UPPER KATANGAAND IN THE ZAMBIAN COPPERBELT

Among the 120 metalliferous deviating features noted in Katanga, only 54 have been explored geobotanically (**Figure 3**). This has led to the establishment of an unpublished preliminary inventory of about 400 higher plants that were collected and deposited at the Belgian National Herbarium (BR). They were observed in eight different plant communities (**Figure 4**). A basic ecological knowledge of several of these species was subsequently inferred from our field observations.

We will discuss the ecological characteristics of the particular flora observed on mine workings in Katanga which includes annual, herbaceous dicotyledons as well as grasses and sedges. It comprises both plants mainly occurring in the natural vegetation of the copper-cobalt outcrops and alien species frequent on Katangan mine workings.

3.1. Widespread species of copper-cobalt outcrops

3.1.1. *Bulbostylis* species. The genus *Bulbostylis* Kunth ex C.B. Clarke (Cyperaceae) comprises about 50 species in the Democratic Republic of Congo,

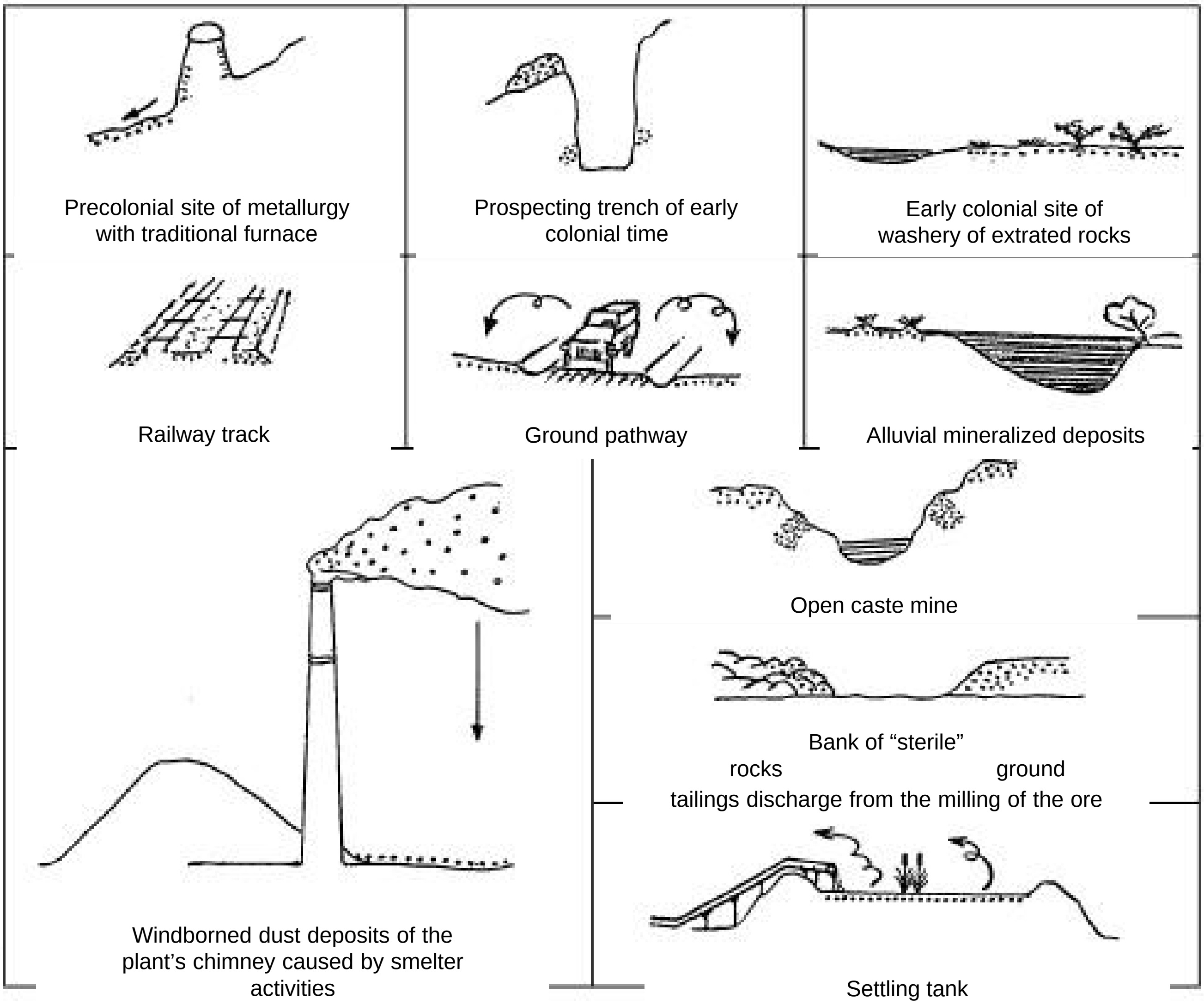


Figure 2. Mining workings and metalliferous pollutions (dotted areas) during precolonial, early colonial and recent period — *Exploitations minières et pollutions métallifères (zones pointillées) durant les périodes précoloniales, coloniales et récentes*.

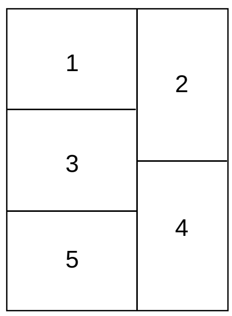
Photo 1. Rest of traditional furnace in miombo woodland in the surroundings of Luishia mine — *Vestige de fourneau traditionnel au sein de la forêt claire, environs de la mine de Luishia.* (Source: F. Malaisse)

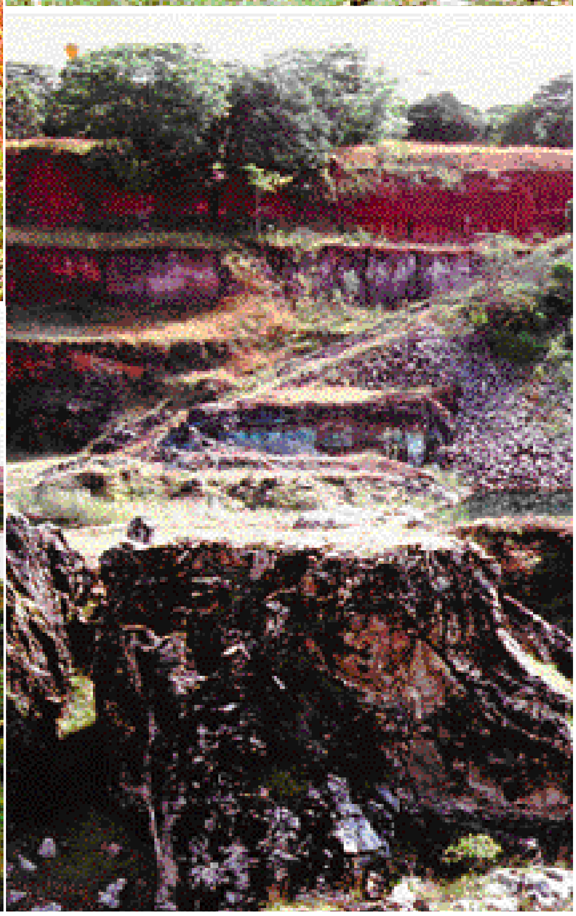
Photo 2. Prospecting trench at Chabara hill — *Tranchée de prospection, colline de Chabara.* (Source: F. Malaisse)

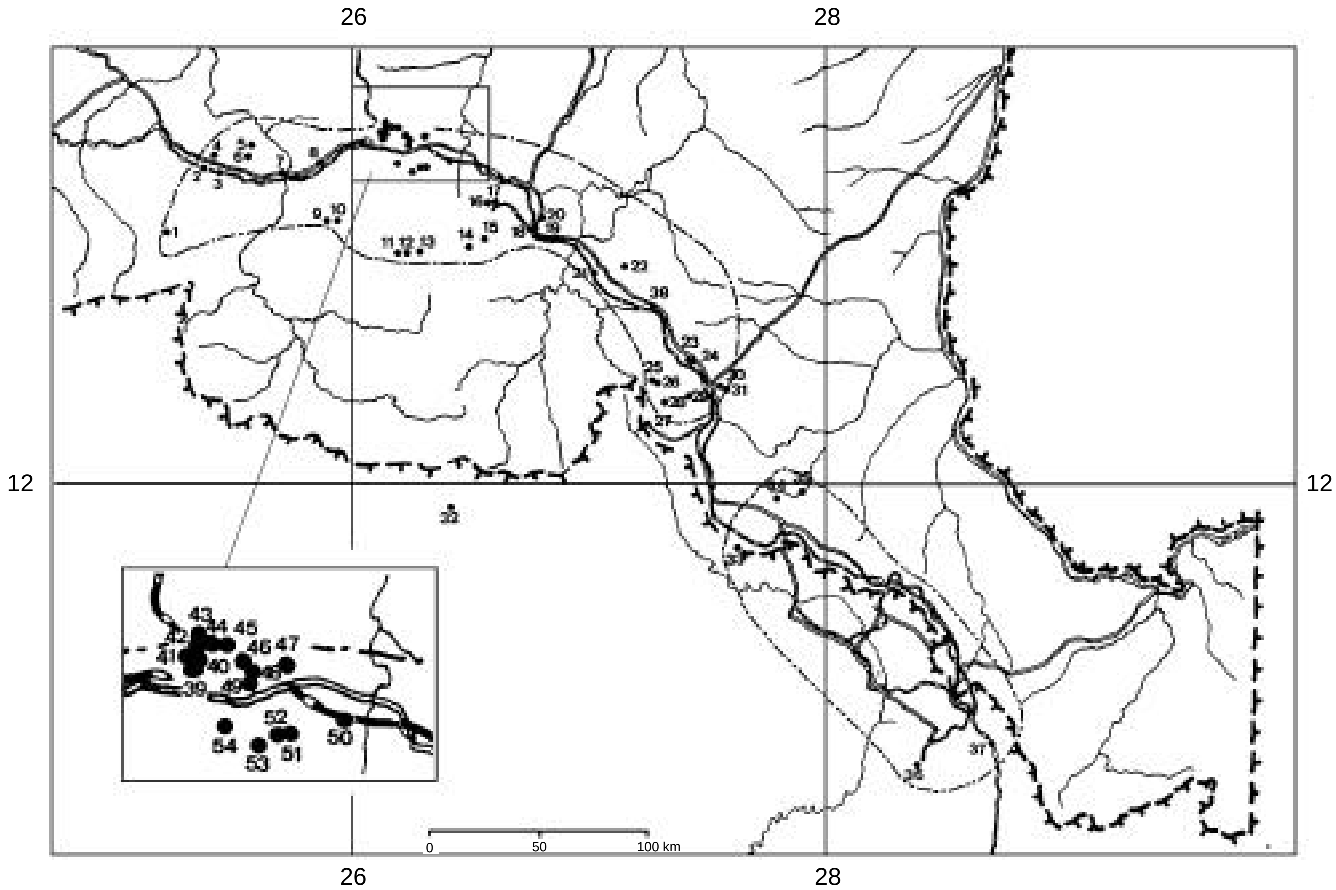
Photo 3. Mineralized rocky upper-side of a trench overgrown with *Bulbostylis cupricola* at Tilwezembe — *Monticule de roches minéralisées provenant d'une tranchée et recouvert de* Bulbostylis cupricola*, Tilwezembe.* (Source: R.R. Brooks)

Photo 4. Open caste mine at Kasombo — *Carrière à ciel ouvert, mine de Kasombo.* (Source: F. Malaisse)

Photo 5. Bank of "sterile" ground tailings discharge near Kolwezi — *Levée de terre "stérile" près de Kolwezi*. (Source: F. Billiet)







1. Kalongwe
2. Dikuluwe
3. Kolwezi
4. Mupine
5. Mutoshi
6. Kilamusembe
7. Tilwezembe
8. Chabara
9. Kasompi
10. Menda
11. Mindingi, Mirungwe
12. Mitonte
13. Swambo
14. Tantara
15. Shinkolobwe
16. Kamoya
17. Kambove
18. Likasi
19. Shituru
20. Kamatanda
21. Luishia
22. Kamwali
23. Lukuni
24. Luiswishi
25. Lupoto
26. Kasonta
27. Kipushi
28. Kasombo
29. Karavia
30. Ruashi
31. Étoile
32. Kansanshi
33. Musoshi
34. Mabaya
35. Kimpe
36. Roan Antelope
37. Bwana Mkubwa
38. Sokoroshe
39. Kakavilondo
40. Goma
41. Tenke
42. Kabwelunono
43. Shimbidi
44. Kavifwafwaulu
45. Kwatebala
46. Mwadikomba
47. Fungurume
48. Mambilima
49. Zikule
50 Kakanda
51. Luita
52. Kahumbwe
53. Kankeru
54. Kela

Figure 3. Presently explored botanical sites — *Sites actuellement explorés d'un point de vue botanique.*

Photo 6. Displaced large blocks of rocks with copper ores at Kansanshi damp — *Amas de gros blocs de pierre riches en minerais de cuivre, site de Kansanshi.* (Source: B. Leteinturier)

Photo 7. Alluvial mineralized deposits colonized by *Rendlia altera*, along the Panda river, downstream the Likasi plant — *Dépôts d'alluvions minéralisées et colonisées par* Rendlia altera*, le long de la rivière Panda, en aval de l'usine de Likasi.* (Source: RR. Brooks)

Photo 8. Mineralized side of a ground pathway reinforced with cupriferous rocks in the vicinity of Lubumbashi — *Bas côté de route minéralisé suite à la consolidation effectuée à l'aide de roches cuprifères, environs de Lubumbashi.* (Source: F. Malaisse)

Photo 9. Site of a former washery of extracted rocks at Étoile mine — *Site d'une ancienne laverie de roches excavées à la mine de l'Étoile.* (Source: F. Malaisse)

Photo 10. Desert atmosphere of Roan Antelope's settling tank. Observe the occurrence of a rare tuft of *Rhynchelytrum repens* — *Ambiance désertique du bassin de décantation de Roan Antelope. Notez la présence d'une touffe solitaire de* Rhynchelytrum repens. (Source: B. Leteinturier)

Photo 11. Lubumbashi plant's chimney's pollution — *Pollution émanant de la cheminée de l'usine de Lubumbashi.* (Source: F. Malaisse)

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7	10
8	11

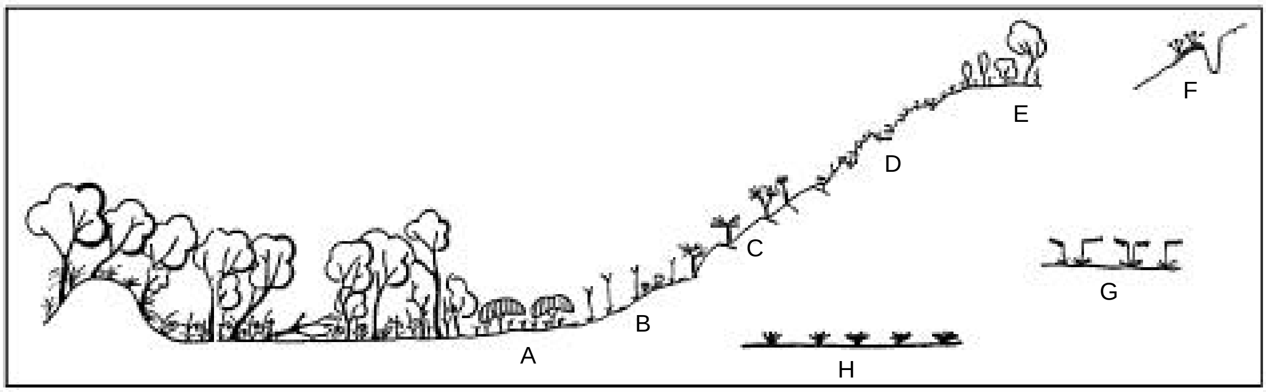


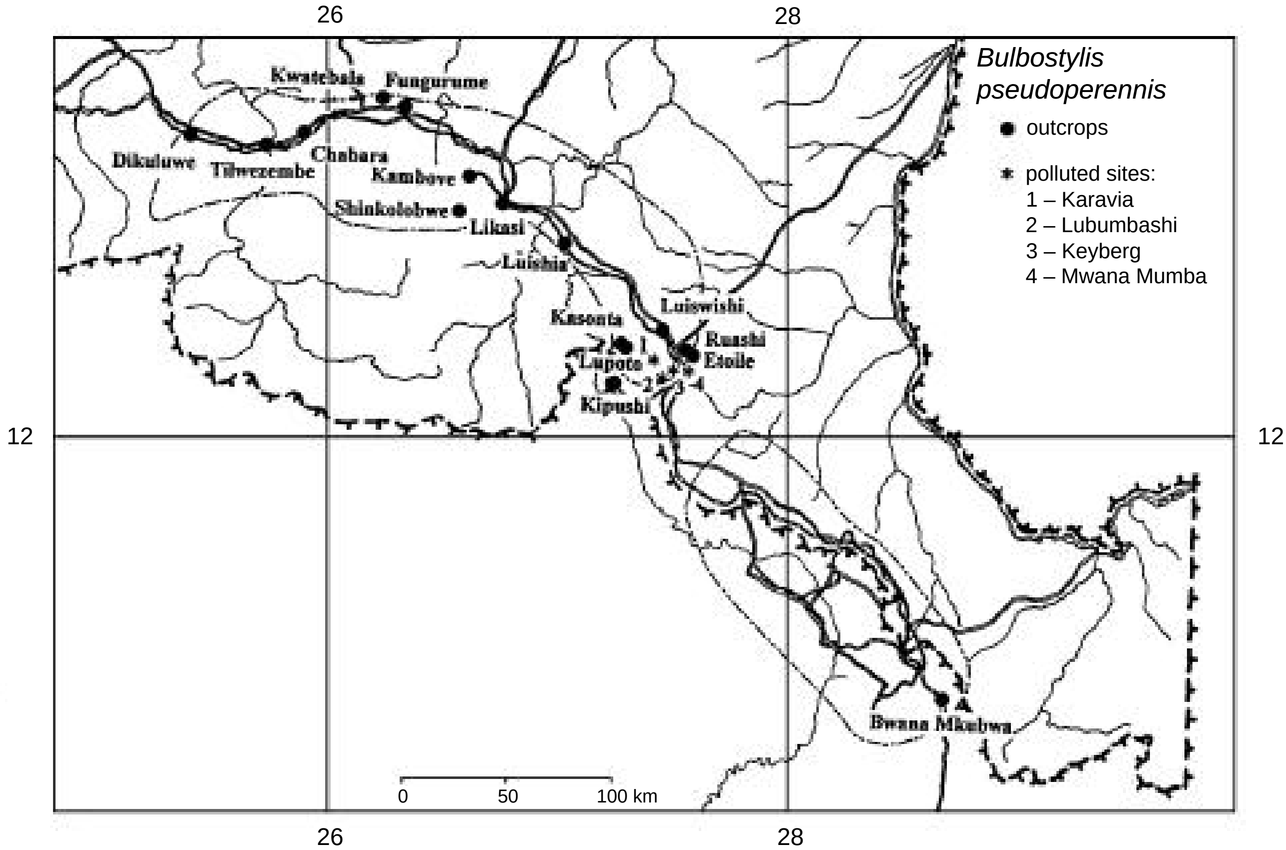
Figure 4. The eight plant communities with metalliferous deviating features in the Katangan Copper Bow and in the Copperbelt — *Les huit communautés végétales des "anomalies" metallifères de l'arc cuprifère katangais et de la Copperbelt*. **A.** *Uapaca robynsii* shrubby savanna belt — *Ceinture de savanne arbusive* ; **B.** *Loudetia simplex-Monocymbium ceresiiforme* steppe savanna with *Acalypha cupricola* as characteristic copper differential — *Savane steppique à* Loudetia simplex-Monocymbium ceresiiforme *avec* Acalypha cupricola *comme différentielle cupricole caractéristique* ; **C.** *Xerophyta* spp. stone-packed steppe — *Steppe enrochée* ; **D.** Crevice vegetation on rocky outcrops — *Vegetation sur affleurements rocheux crevacés* ; **E.** *Hymenocardia acida* wooded savanna — *Savane boisée* ; **F.** *Haumaniastrum robertii* sward on reworked copper soil — *Pelouse sur sol cuprifère remanié ;* **G.** *Rendlia altera* sward on compacted soil — *Pelouse sur sol compact* ; **H.** *Bulbostylis pseudoperennis* sward —*Pelouse*.

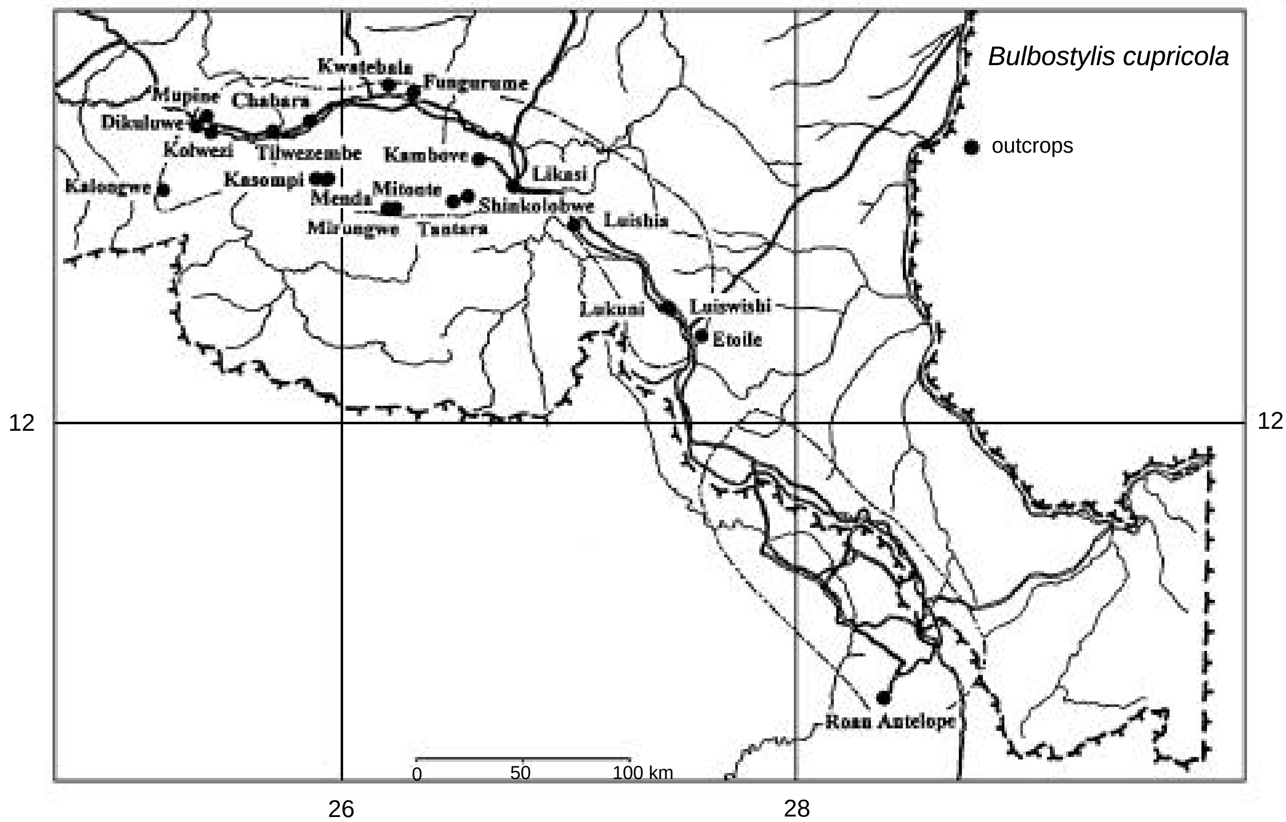
Rwanda and Burundi (Goetghebeur, 1984), three of them being currently observed on copper-mineralized outcrops: *Bulbostylis cupricola* Goetgh., *B. pseudoperennis* Goetgh. and *B. fusiformis* Goetgh. (Goetghebeur, 1984; Goetghebeur, Coudijzer, 1985). Two of them are of great interest with respect to ecological conditions.

Bulbostylis pseudoperennis (**Photo 12**) was only described in 1985 and before was overlooked and confused with *B. mucronata* C.B. Clarke. It is a species restricted to copper-cobalt outcrops and to mine-polluted areas, both operational and derelict. It has only been collected from 16 outcrops (**Figure 5**) but has been observed through all the Katangan Copper Bow, at least on half of the ore bodies visited by one of us (FM). It is a therophyte which has escaped from mineralized sites and may at present be observed on reworked soils with slight to heavy copper enrichment. This is, for instance, the case of the surrounding soils of the Gécamines plant at Lubumbashi, the nearby Zoological Garden of Lubumbashi and the Cemetery of Pioneers in the vicinity of the Étoile Mine. Furthermore it appears regularly along the verges of some roads loaded with "sterile" rocks (in fact slightly elevated in copper), at Katuba and Karavia for instance, as already stated by Brooks and Malaisse (1985), as well as in the downwind sector of the Lubumbashi plant stack on skeletal soils. It is still present on sites of precolonial metallurgical work at Mwanamumba (De Plaen *et al*., 1982). In these reworked sites the carpets of *B. pseudoperennis* are frequently observed in bare areas, slightly depressed with sand accumulation and water stagnation after heavy rainfall. The slender root system of this annual is perfectly adapted to these microtopographic conditions. Moreover the old tufts of this annual plant offer excellent microconditions for the germination of its seeds the following year, as indicated by its specific epithet. Furthermore, *B. pseudoperennis* is a copper and cobalt hyperaccumulator which can contain up to 7,783 and 1,373 $\mu g \cdot g^{-1}$ metal in its dry matter respectively (Brooks *et al.*, 1987).

Bulbostylis cupricola (**Photo 13**) is another therophyte of interest. It was first described in 1984 and resembles *B. abortiva* (Steud.) C.B. Clarke with which it was for a long time confused. This slender annual has only been observed on mineralized soils. It has been collected from 21 Cu/Co sites (**Figure 6**) and is a second species restricted to Katango-Zambian copper outcrops. In the Shinkolobwe area it colonizes, along with another annual *Haumaniastrum katangense*, the copper/cobalt/uranium mine dumps of Boring IV, producing a bispecific open sward (Malaisse *et al.*, 1994). Respective copper, cobalt and nickel contents of the soil are 5,500, 9,900 and 9,800 $\mu g \cdot g^{-1}$ oven-dried soil. According to our present knowledge the plant prefers rocky skeletal reworked and dry substrates. In this last situation, even if its competitive power is weak, the plant can develop monospecific carpets. This plant contains slightly elevated heavy metal contents, ranging about 20-948 $\mu g \cdot g^{-1}$ copper and 85-771 $\mu g \cdot g^{-1}$ cobalt (Brooks *et al.*, 1987).

Bulbostylis fusiformis, a rather slender annual, with the habit of a robust *B. pseudoperennis*, appears restricted to two neighbouring copper outcrops, the Luiswishi (= Kiswishi) mine, where it was twice collected in the bottom, along and in the vicinity of a prospecting





Figures 5 and 6. Localisation of the collection cupriferous sites of *Bulbostylis pseudoperennis* and *Bulbostylis cupricola* — *Cartes de répartition de* Bulbostylis pseudoperennis *et de* Bulbostylis cupricola *sur sites cuprifères*.

trench, and at the Kasonta mine, where it was collected only once. No data about metal uptake are available.

3.1.2. *Haumaniastrum* species. The genus *Haumaniastrum* P.A. Duvigneaud and Plancke was recognized in 1959; it belongs to the Lamiaceae family. According to Paton (1997), it comprises six sections, 35 species, five subspecies and three varieties. Its centre of diversity is in Katanga. There, several *Haumaniastrum* taxa occur on mineralized soils, most of them being perennials, namely *H. polyneurum* (S. Moore) P.A. Duvigneaud and Plancke, *H. prealtum* (Briq.) P.A. Duvigneaud and Plancke var. *homblei* (De Wild.) A.J. Paton, *H. rosulatum* (De Wild.) P.A. Duvigneaud and *H. timpermanii* (P.A. Duvigneaud and Plancke) P.A. Duvigneaud and Plancke. Nevertheless, two annuals are of interest as geobotanical indicators of copper/cobalt mineralization, particularly in the Katangan Copper Bow (Paton, Brooks, 1996).

Haumaniastrum katangense (S. Moore) P.A. Duvigneaud and Plancke (**Photo 14**) is a therophyte. Malaisse and Brooks (1982), as well as Paton and Brooks (1996) have already discussed several aspects of its particular ecology emphasizing its ability to colonize mining sites, mine dumps, old smelting sites, roadsides, railway tracks as well as places of precolonial industry. *H. katangense* is usually recorded on rocky ground or slopes (Paton, 1997) and is very widely distributed on the copper-rich soils of Upper Katanga and Western Zambia (**Figure 7**). The copper and cobalt content presents a wide range of values: 29–8,356 and 5–1,976 $\mu g \cdot g^{-1}$ respectively (Brooks *et al.*, 1987).

Haumaniastrum robertii (Robyns) P.A. Duvigneaud and Plancke (**Photo 15**), another annual observed on copper-cobalt soils, seems to be largely allopatric with the first species. With the exception of Karavia mine, it is restricted to the north-western part of the Katangan Copper Bow (Paton, 1997) (**Figure 7**). The plant was collected in 1933 by Quarré at Karavia, in the vicinity of Lubumbashi, more than a hundred kilometres from its other occurrences. The Karavia mine is today completely worked out, so that no metallophyte flora may still be observed there. The indigenous nature of this occurrence is thus impossible to discuss at present. Nevertheless, the endemic character of this plant is obvious. It shows an overall

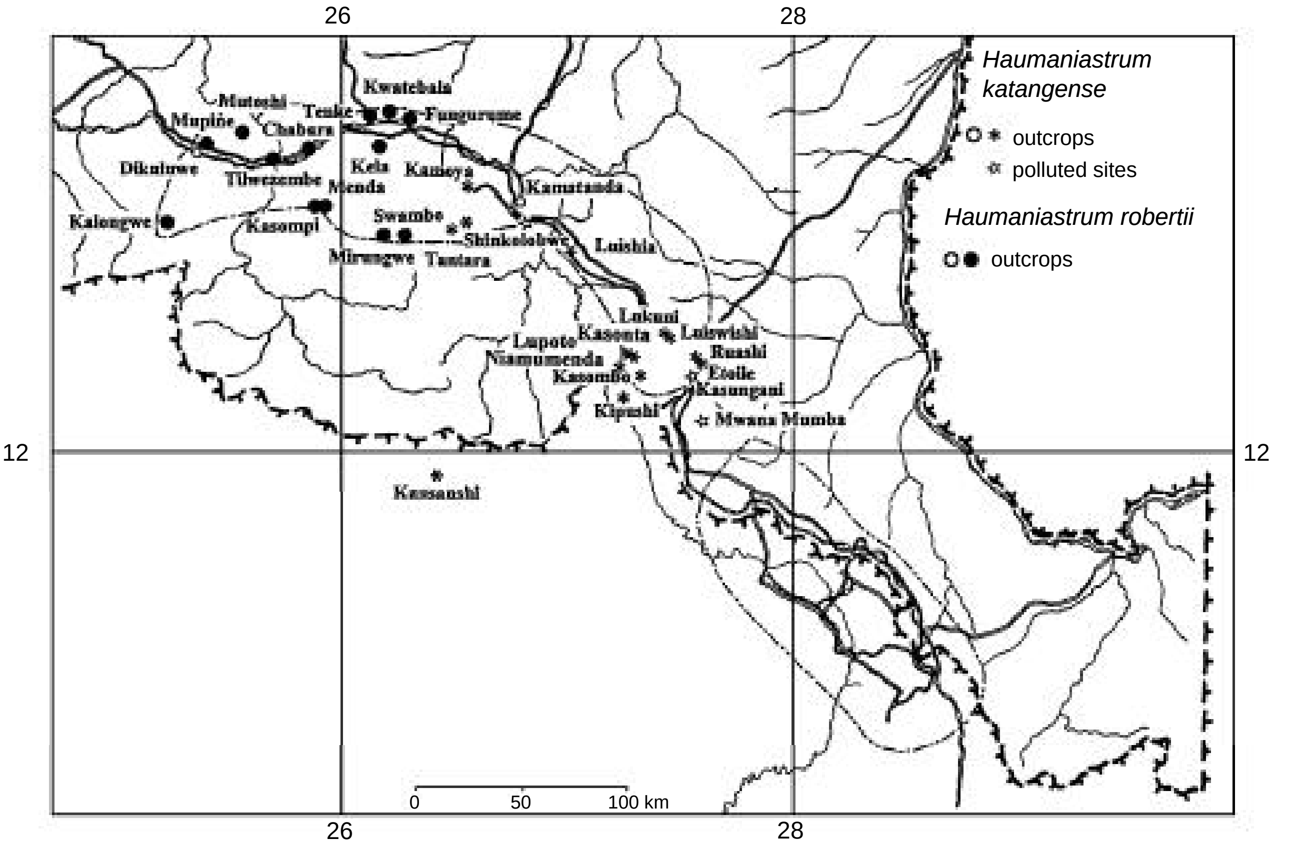


Figure 7. Localisation of the collection cupriferous sites of *Haumaniastrum katangense* and *Haumaniastrum robertii* — *Carte de répartition de* Haumaniastrum katangense *et de* Haumaniastrum robertii *sur sites cuprifères.*

preference for the reworked heavy mineralized banks obtained from the excavation of trenches. It is a good colonist of skeletal rocky soils, mainly those occurring on medium to steep slopes.

Copper and cobalt contents of 46–2,070 and 98–9,950 µg.g-1 respectively have been reported for this species (Brooks *et al.*, 1987).

3.1.3. *Faroa* species. The genus *Faroa* (Gentianaceae) was first described in 1869 by Welwitsch on the basis of a plant collected in Angola. In 1973, 17 species were recognized by Taylor, who pinpoints the conspicuously restricted distribution of most species with a high concentration of taxa in the Katanga-Zambia "Copperbelt" region. Bamps (1987) reported ten taxa in Katanga putting the grand total for *Faroa* to twenty species. The genus Faroa comprises many small annual species (therophytes) observed in open conditions such as temporary pools on lateritic pans, reduced soil pockets in siliceous cellular rocks, savannas, steppish savannas on Kalahari sands and dambos (seasonaly flooded savannas). For example, it should be noted that *Faroa fanshawei* P. Taylor is known from quartzite kopjes, *F. richardsiae* P. Taylor from crevices in granite rocks on inselbergs in the Tunduru district of Tanzania, whereas *Faroa acaulis* R.E. Fr. and *F. salutaris* Welw. has been observed on the steppish savannas overlying the Kalahari sands of the high plateaus as well as on dembo and savannas of the medium plateau. Furthermore, *F. involucrata* (Klotzsch) Knobl. has been observed in rocky situations, apparently associated with mineral outcrops at low altitude in Moçambique (Taylor, 1973).

The ability of several *Faroa* species to colonize skeletal, heavily mineralized substrates is therefore not surprising. *Faroa malaissei* Bamps has until now been observed only on siliceous cellular rocks of Fungurume and Luita mines (**Figure 8**). Another species, *Faroa affinis* P. Taylor was observed in a copper clearing at Mabaya (**Figure 8**). *Faroa chalcophila* P. Taylor is restricted to two mines around Lubumbashi, namely Étoile and Luiswishi (**Figure 8**). This annual germinates late in the main rainy season, assuring its development during the cold dry season. The plant colonizes the horizontal mine workings with high copper content forming mostly monospecific carpets. In somes places *Buchnera henriquesii* Engl. penetrates the *F. chalcophila* swards. *F. chalcophila* is an accumulator of copper and cobalt with respectively 84–665 and 45–382 µg·g-1 metal in its shoot dry matter.

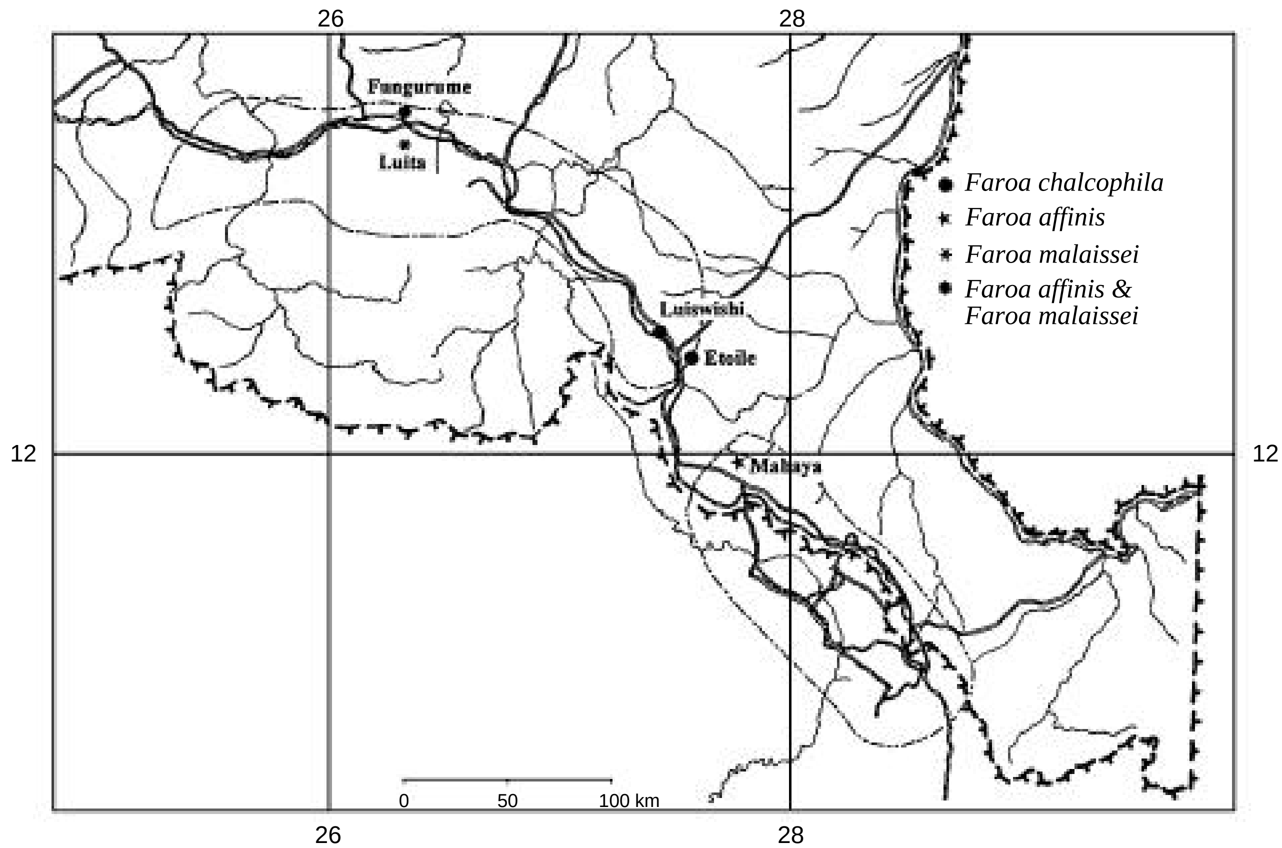


Figure 8. Localisation of the collection cupriferous sites of *Faroa malaissei*, *Faroa affinis* and *Faroa chacophila* — *Carte de répartition de* Faroa malaissei, Faroa affinis *et* Faroa chacophila *sur les sites cuprifères*.

3.1.4. *Crepidorhopalon* species. The genus was suggested in 1989 by Fischer for several *Lindernia* species. *Crepidorhopalon tenuis* (S. Moore) Eb. Fisch. (**Photo 16**) belongs to the Lindernieae tribe of the Scrophulariaceae. It has been collected in South-west Tanzania and the Northern Province of Zambia and Upper Katanga (Fischer, 1992). For the last territory, this elegant annual has been observed on the verges of surfaced roads (exploitation pads) in the vicinity of Lubumbashi, as well as on mine workings (**Figure 9**), and furthermore in new sites in grasslands notably on the high plateaus. *C. tenuis* is an accumulator of copper and cobalt with respectively 927 and 1,113 $\mu g \cdot g^{-1}$ metal on a dry weight basis (Brooks *et al.*, 1987).

Crepidorhopalon perennis (P.A. Duvigneaud) Eb. Fisch., a perennial hyperaccumulator of copper, has only been observed at the Étoile Mine and the nearby Ruashi Mine where it grows slowly on heavily mineralized soils (**Figure 9**). It is a hyperaccumulator of copper and cobalt with respectively up to 9,322 and 2,300 $\mu g \cdot g^{-1}$ metal in its shoots.

3.2. Other species frequent on Katangan mine workings

3.2.1. Pteridophyta. Another plant of interest is *Pteris vittata* L. (**Photo 17**), a vigorous perennial fern. It prefers shade in rock crevices as well as the fresh bottom areas of irregular surfaces. It has been found in rocky steppe-savanna on steep slopes at the Étoile Mine, Lukuni, Tantara and Swambo orebodies. It reaches its maximum development on copper-rich damp sandy clays. Such substrates are found around the Étoile mine where minerals were washed in the early colonial period. The mineral content of *P. vittata* leaves is up to 200 and 73 $\mu g \cdot g^{-1}$ of copper and cobalt respectively on a dry weight basis (Brooks, Malaisse, 1985). *P. vittata* has been reported by Hall (1970) as colonising blackish hills of waste on five gold mines in Southern Ghana at Tarkwa, Pretea, Bibiani, Obuasi and Konongo. With the exception of these sites, this fern is entirely absent throughout the rest of tropical West Africa. Hall (1970) concluded that the distribution

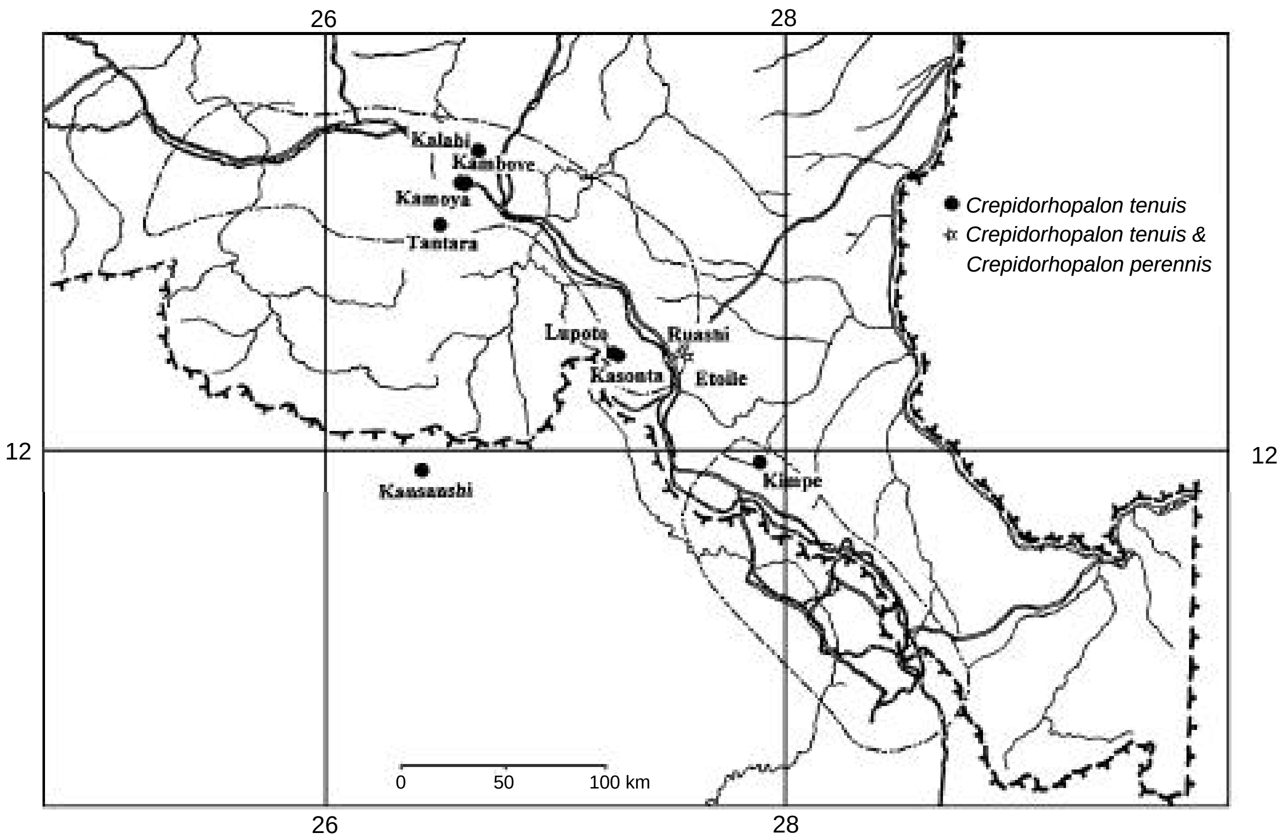


Figure 9. Localisation of the collection cupriferous sites of *Crepidorhopalon tenuis* and *Crepidorhopalon perennis* — *Carte de répartition de* Crepidorhopalon tenuis *et* Crepidorhopalon perennis *sur site cuprifère*.

of this fern was controlled by its requirement of a well-drained rocky substrate, cool at depth, but exposed to sunshine, a condition not normally found in tropical West Africa except where mining activities have produced these specific conditions.

The frequent presence of *Nephrolepis undulata* (Afzel. ex Sw.) J. Sm. on sites of precolonial metallurgy has been reported from Dikulushi as well as from Luishia (Malaisse *et al.*, 1985). The reported metal contents of *N. undulata* fronds are 36 and 45 $\mu g \cdot g^{-1}$ dry weight of respectively copper and cobalt (Brooks, Malaisse, 1985).

The processing plant at Lubumbashi was constructed in 1911 and the chimney was successively raised. The non-mineralized surrounding soils have therefore become contaminated with the smelter fallout over a period of more than eighty years. At the foot of the chimney, the Lubumbashi river banks are colonized by a dense carpet of *Equisetum ramosissimum* Desf. var. *ramosissimum* (for which the following metal contents of respectively copper and cobalt have been reported: 66 and 59 $\mu g \cdot g^{-1}$ on a dry weight basis (Brooks, Malaisse, 1985). This horsetail is rare in Katanga, being only known from one other locality along the Tanganyika Lake at Kalemie.

3.2.2. Asteraceae. A further set of plants observed on mine workings are relevant to the ruderal flora. The most dynamic species, according to our observations, are *Anisopappus chinensis* (L.) Hook. & Arn. subsp. *chinensis* and *Vernonia petersii* Oliv. & Hiern ex Oliv. On slightly mineralized soils *Bidens oligoflora* (Klatt) Wild is frequent.

Vernonia petersii has been regularly observed along tracks and in the villages on the Kalahari sandy high plateaus of Katanga. Similarly it has been observed along the verges of working dirttracks of the copper mines at Étoile, Kasombo and Lupoto, as well as at Mwana Mumba, a place of precolonial metallurgical works. Brooks *et al.* (1987) report 1,555 and 57 $\mu g \cdot g^{-1}$ dry weight of copper and cobalt respectively in leaves of *V. petersii* for the site of Lupoto.

Anisopappus chinensis subsp. *chinensis* (**Photo 18**) is an annual still observed on medium-mineralized soils but it is more vigorous on light mineralization. It is frequent at Étoile Mine. Outside mine sites, the plant shows a broad distribution, essentially palaeotropical, but extending to China. Respective copper and cobalt contents of 1,657 and 919 $\mu g \cdot g^{-1}$ have been reported (Brooks *et al.*, 1987).

Bidens oligoflora (**Photo 19**) is a good representative of the ruderal flora of Katanga, where it appears as a dynamic colonist. It is largely present in peri-urban derived savannas. The plant is also present on mineralized workings at several mines. It was collected at Étoile, Kasonta, observed at Ruashi and Ruwe, as well as on precolonial copper smelting sites (Luishia for instance). Its range is restricted to Central Africa (P. R. Congo, Angola, D. R. Congo and Zambia). The observed copper and cobalt contents for a specimen from Kasonta are low, respectively 332 and 9 $\mu g \cdot g^{-1}$, always on a dry basis (Brooks *et al.*, 1987).

3.2.3. Grasses. *Rendlia altera* (Rendle) Chiov. (**Photo 20**) is a vigorous perennial grass developing large carpets. It has been regarded as a copper endemic and quoted as *Rendlia cupricola* P.A. Duvigneaud. It is frequent on heavy metal polluted soils. For example, the river Pande, in the vicinity of Buluo, has established a sandy alluvial bank. As the river is polluted upstream by the Likasi plant, those sands have a high copper and cobalt content (1.1 and 0.13% respectively). *R. altera* is the only plant colonizing these alluvial deposits. The plant has also been found in grey colluvia near the River Mulunguishi, a site likewise polluted by metalliferous muds from a treatment plant. Similarly the plant shows a dynamic pattern on horizontal mineralized reworked surfaces, where it frequently produces dense carpets (Ruashi, Étoile, Luiswishi, Fungurume, Dikulushi, etc.). Furthermore, it tolerates soils compacted by lorries, logging, footpaths, etc., and consequently temporary water stagnation. Nevertheless, its autecology requires further research in order to more fully understand its distribution and habitat requirements. Respective copper and cobalt contents of 394 and 13 $\mu g \cdot g^{-1}$ have been reported (Brooks *et al.*, 1987).

4. DISCUSSION

On the basis of our observations, several plants, mostly annuals, appear suitable for primary colonization of metalliferous workings. The importance of species belonging to some specific genera has been demonstrated. Some of these appear to be able to participate in the important early stages of greening of mineral wastes. Taking into account the level of soil mineralization on the one hand and soil moisture conditions on the other, it already seems possible to establish guidelines for a first selection of plants according to the respective ecological groups recognized (**Table 1**).

Several new lines of investigation should be put in place in order to increase our knowledge in this area. Firstly, the two-way table should be completed for further species. Secondly, seed germination experiments and pot trials must be carried out in order to obtain more accurate information regarding plant response to heavy metal mineralization, plant mineral uptake and *in situ* vegetation growth and dynamics. The processes of natural revegetation of metalliferous mine wastes are in urgent need of more knowledge.

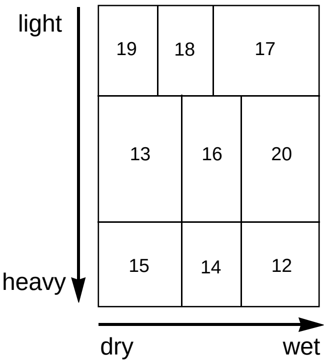


Photo 12. *Bulbostylis pseudoperennis*, Étoile mine (× 5/4). (Source: RR. Brooks)

Photo 13. *Bulbostylis cupricola*, Roan Antelope Luanshya (× 1). (Source: F. Malaisse)

Photo 14. *Haumaniastrum katangense*, Kansanshi Hill — *Colline de Kansanshi* (× 1/3). (Source : F. Malaisse)

Photo 15. *Haumaniastrum robertii*, Mutoshi (× 1/4). (Source: M. Schaijes)

Photo 16. *Crepidorhopalon tenuis*, Kansanshi Hill — *Colline de Kansanshi* (× 1). (Source: F. Malaisse)

Photo 17. *Pteris vittata*, Roan Antelope Luanshya (× 1/4). (Source: F. Malaisse)

Photo 18. *Anisopappus chinensis* subsp. *chinensis* (× 1/4). (Source: F. Malaisse)

Photo19. *Bidens oligoflora*, Fungurume (× 1/8). (Source: F. Malaisse)

Photo 20. *Rendlia altera*, Luiswishi (× 1). (Source: F. Malaisse)

Table 1. Indication of the most charateristic taxon corresponding to each ecological group recognized on metalliferous mine workings (For illustration, see page 40) — *Mention de l'espèce la plus caractéristique pour chacun des groupes écologiques reconnus sur travaux miniers métallifères (illustration, voir page 40).*

Soil mineralization	**Soil conditions**		
	dry	**medium**	**temporarily wet**
light	*Bidens oligoflora* (**19**)	*Anisopappus chinensis* subsp. *chinensis* (**18**)	*Pteris vittata* (**17**)
medium	*Bulbostylis cupricola* (**13**)	*Crepidorhopalon tenuis* (**16**)	*Rendlia altera* (**20**)
heavy	*Haumaniastrum robertii* (**15**)	*Haumaniastrum katangense* (**14**)	*Bulbostylis pseudoperennis* (**12**)

Bibliography

Bamps P. (1987). Un nouveau *Faroa* (*Gentianaceae*) du Zaïre. *Bull. Jard. Bot. Natl. Belg.* **57**, p. 479–480.

Brooks RR., Malaisse F. (1985). *The heavy metal tolerant flora of South-Central Africa - a multidisciplinary approach*. Rotterdam: Balkema, 199 p.

Brooks RR., Naidu SM., Malaisse F., Lee J. (1987). The elemental content of metallophytes from the copper/cobalt deposits of Central Africa. *Bull. Soc. R. Bot. Belg.* **119** (2), p. 179–191.

De Plaen G., Malaisse F., Brooks RR. (1982). The copper flowers of Central Africa and their significance for prospecting and archeology. *Endeavour* N.S. **6** (2), p. 72–77.

Fischer E. (1992). *Systematik der Afrikanischen Lindernieae (*Scrophulariaceae*).* Tropische und subtropischen Pflanzenwelt **81** Mainz, Deutschland: Akad. Wissenschaften Literatur, 365 p.

François A. (1973). *L'extrémité occidentale de l'arc cuprifère shabien. Étude géologique.* Likasi : Rép. Dém. Congo: Gécamines, 97 p.

Goetghebeur P. (1984). Studies in *Cyperaceae* 4. New species and a new combination in Central African *Bulbostylis. Bull. Jard. Bot. Natl. Belg.* **54** (1/2), p. 91–104.

Goetghebeur P., Coudijzer J. (1985). Studies in *Cyperaceae* 5. The genus *Bulbostylis* in Central Africa. *Bull. Jard. Bot. Natl. Belg.* **55** (1-2), p. 207–259.

Hall JB. (1970). *Pteris vittata Linn.* a gold mine fern in Ghana. *Niger. Field* **35**, p. 1–9.

Malaisse F., Brooks RR. (1982). Colonisation of modified metalliferous environments in Zaïre by the copper flower *Haumaniastrum katangense*. *Plant Soil* **64** (2), p. 289–293.

Malaisse F., Marenthier M., Grégoire J. (1985). Géochimie, phytogéographie et phytogéochimie dans l'exploration métallifère de la région Dikulushi-lac Moëro (Shaba méridional, Zaïre). *Geo-Eco-Trop* **9** (3-4), p. 187–205.

Malaisse F., Brooks RR, Baker AJM. (1994). Diversity of vegetation communities in relation to soil heavy metal content at the Shinkolobwe copper/cobalt/uranium mineralization, Upper Shaba, Zaire. *Belg. J. Bot.* **127** (1), p. 3–16.

Paton A. (1997). A revision of *Haumaniastrum* (*Labiatae*). *Kew Bull.* **52** (2), p. 293–378.

Paton A., Brooks RR. (1996). A re-evaluation of *Haumaniastrum* species as geobotanical indicators of copper and cobalt. *J. Geochem. Explor.* **56**, p. 37–45.

Taylor P. (1973). A Revision of the Genus *Faroa* Welwitsch. *Garcia de Orta*, Sér. Bot. (Lisboa), **1** (1-2) p. 69–82.

(15 ref.)