Modelling realized niche of metallophyte species along copper and cobalt gradients on Katangan copper hills



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In South Central Africa were identified more than 650 plant species tolerant to heavy metals, several of which endemic to Katanga and endangered by mining activities. These metallophytes are distributed over a hundred hills containing high copper and cobalt concentrations (20 to 10000 mg/kg for Cu and 2 to 1000 mg/kg for Co). In 1963, Duvigneaud and Denaeyer-De-Smet qualitatively described the realized niche of some of these species. Here, we use a quantitative approach to characterize those species niche (defined as a n -dimensional hypervolume characterising the set of ecological conditions required for development of a species) and test the two following hypotheses.

Materials and methods

Study area – Data collection

172 vegetation relevés (1m²) were made using a systematc sampling on three hills on the Katangan Copper Belt (Congo D.R.): *Fungurume* V (10°36' S ; 26°17' E), Kafifwafwaulu (10°34' S ; 26°9' E.), Kazinianga (26° 25' E, 10° 62' S). Species







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Hypothesis

The realized niche of metallophyte are uniformly distributed along the coppercobalt gradient of katangan hills

Niche amplitudes increase with niche optima for copper and cobalt factors

The Katangan Copper Belt

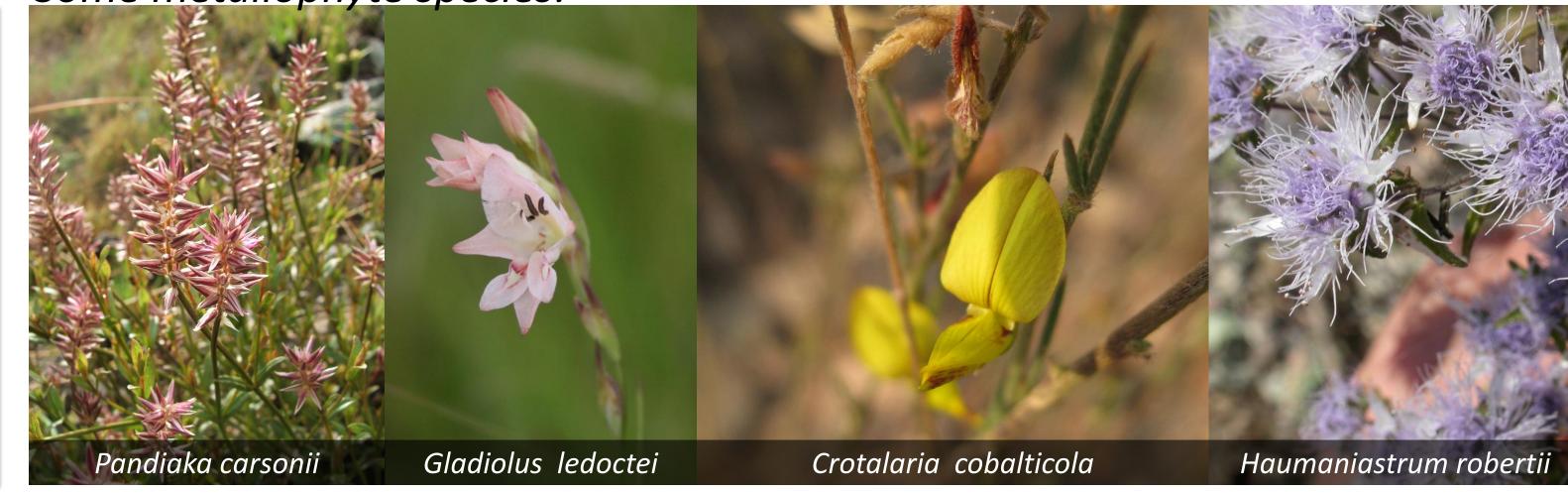


presence/absence was recorded, and topsoil Cu and Co concentrations were measured.

Modelling and statistical methods

Species distribution models were made for Cu and Co concentrations, using generalized additive models (GAM) with 3 df in R interface (JUICE 7.0 - 'mgcv' library). Amplitude limits were determined by extreme values of area under curve (AUC – 80%). Analyses were performed for species present on more than 8 sites.

Some metallophyte species:

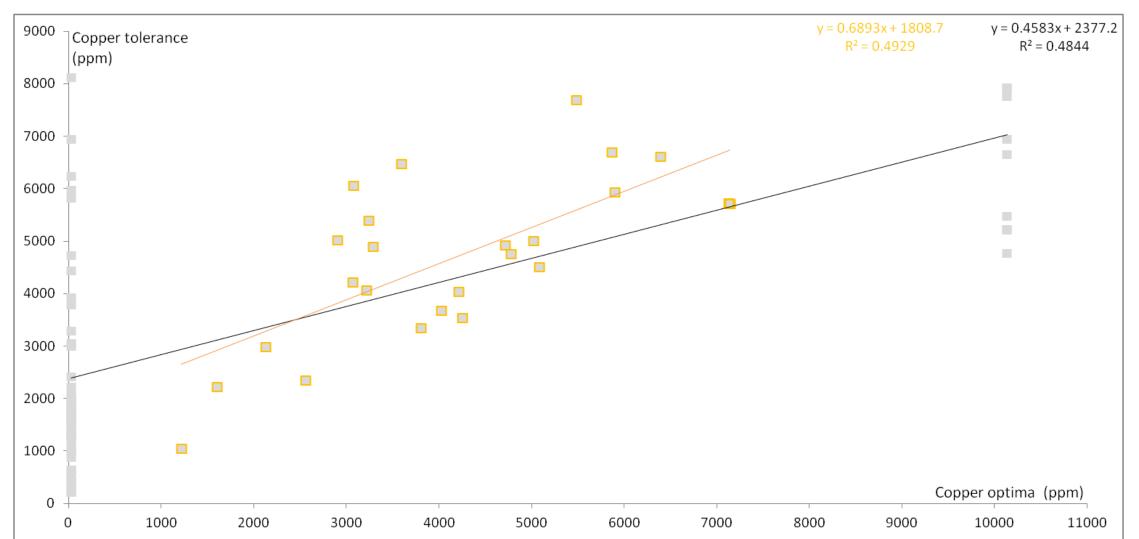


Results

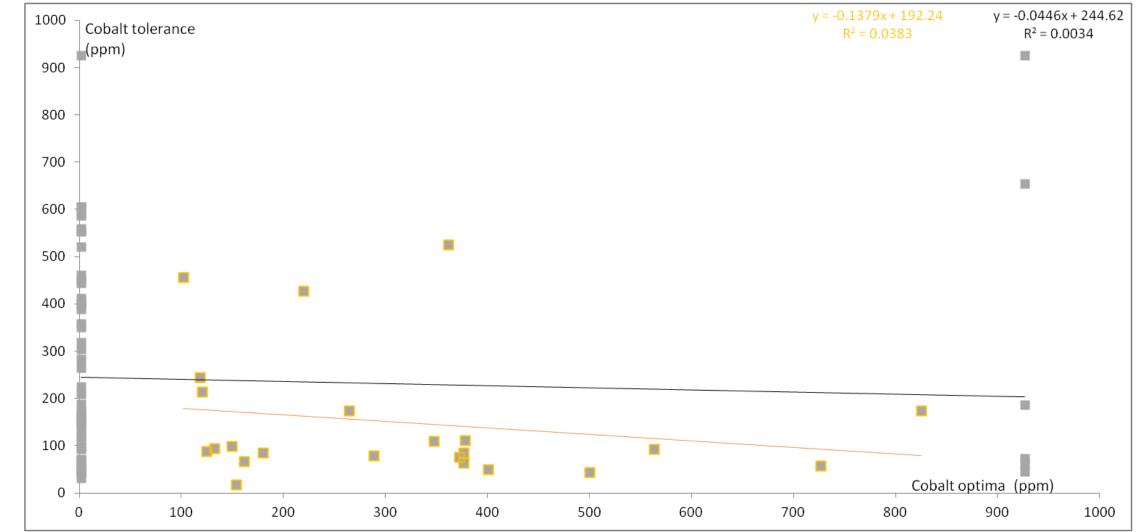
1 - Optima and amplitude of realized niches is estabished for 80 species (9 endemic species) for Cu and Co gradients. In both cases, 3 groups of species can be identified : one for which the minimum is equal to the lowest values of the gradient (Group 1), one for which the maximum is equal to the highest values of the gradient (Group 3) and one group with a intermediate behavior (Group 2). For the copper, species are not distributed uniformly on the gradient.

Tristachya superba 🍋 Olax obtusifolia 🖛 Copper gradient (ppm) Cobalt gradient (ppm) Cyperus margaritaceus 🚥 Aeschynomene pyamaea 🚥 Olax obtusifolia 🚥 Droogmansia pteropus Vernonia aff.turbinella 💻 Crotalaria sp.1 • Indigofera sp.2 • Aeschynomene katangensis • Chamaecrista mimosoides 🔹 👘 Sporobolus cf mildbreadii 🚥 🚽 Commelina sp.1 Digitaria sp. 💶 🔤 Aeschynomene katanaensis • Tristachya superba 💶 Endostemon dissitifolius 🔹 Sphenostylis sp. Aeschynomene pygmaea Cyperus maraaritaceus Rhytachne rottboellioides 🚥 Friospermum abyssinicum • Drooamansia pteropus 🚥 hamaecrista mimosoides 💶 💳 Scleria bulbifera 🚥 Tristachva beauaertii 🔹 👘 Murdannia simplex 🚥 Commelina sp.1 • Schizachyrium brevifolium 🚥 Crotalaria araenteotomentosa • Hvparrhenia sp. 💻 Vernonia suprafastiaiata • Cyperus cf. kibweanus 1 • Sacciolepis transbarbata 🗨 🚽 🖉 Sphenostylis sp. 🚥 Cryptosepalum maraviense • Tristachva beauaertii 🖷 Bulbostylis macra 🔹 rotalaria araenteotomentosa Commelina sp.4 • Haumaniastrum rosulatum Striga asiatica 🔹 Striaa asiatica 💷 Rhvtachne rottboellioides 🔍 🚽 🚽 Eriospermum abyssinicum 🚥 Poaceae sp.2 • Oxalis semiloba 🚥 Oxalis semiloba • Eriosema shirense 💻 Schizachyrium brevifolium 🔍 Poaceae sp.2 Murdannia simplex • Ocimum sp.1 Vernonia aff.turbinella 🔹 Hibiscus rhodanthus 🖣 Group 1 laumaniastrum praealtum • Group 1 Loudetia superba 🔳 Ocimum sp.1 • Pimpinella acutidentata 🚥 Endostemon dissitifolius 🔹 Cryptosepalum maraviense 💻 Ocimum vanderystii 🔹 👘 Commelina sp.3 🚥 Polvaala petitiana 🗨 Bulbostylis macra 💻 Scleria bulbifera 🚥 Crotalaria sp.1 • aumaniastrum rosulatum 💶 Vernonia suprafastigiata 🖣 Commelina sp.3 🚥 Buchnera randii 🖣 Friosema shirense 🚥 Sacciolepis transbarbata Indiaofera sp.2 Haumaniastrum praealtum Cvperus cf.kibweanus 1 Sporobolus cf mildbreadii Heteropoaon contortus Heteropoaon contortus *Crotalaria cobalticola Brachiaria serrata Pimpinella acutidentata 🔹 Cyanotis aff. Cupricola Gladiolus gregarius Gladiolus gregariu Loudetia simple. Loudetia superb Hyparrhenia diplandı Digitaria cf uniglumis Diaitaria sp. `yanotis aff. Cupricola Polygala petitiana Diheteropogon grandiflorus Diheteropoaon arandiflorus Brachiaria serrat Commelina sp.4 Hibiscus rhodanth Euphorbia zambesiana *Triumfetta welwitschii Justicia elegantula Bulbostylis filamentosa Buchnera trilobat Group 2 *Acalypha cupricola Oxalis obliauit lolophium marthozianum Monocvmbium ceresiiforma Chloris sp *Acalypha cupricola Digitaria cf uniglumis

2 – The two regressions show different results : For copper, a proportional relationship can be identified between tolerance and optima along gradient. For cobalt, no relationship are highlighted.



Linear regression between tolerance (amplitude) and optima along copper gradient for all species (grey) and group 2 (orange). Regressions are significant (P<0.001).



Buchnera trilobata		•	Giudiolus leubelei		Group 2
Rendlia altera		•	Sporobolus congoensis		Group 2
Iridaceae sp.2		•	Thesium quarrei		
Oxalis obliquifolia			Bulbostylis filamentosa	•	
Pandiaka carsonii		•	Andropogon schirensis	•	
Xerophyta equisetoides		•	Hyparrhenia diplandra	•	
Chlorophytum subpetiolatum			lpomoea recta	· · · · · · · · · · · · · · · · · · ·	
Anisopappus davyi			Cyanotis longifolia	•	
Monocymbium ceresiiforme			**Ascolepis metallorum	•	
Thesium quarrei			Pandiaka carsonii	•	
**Ascolepis metallorum			Anisopappus davyi	•	•
			Chlorophytum subpetiolatum	· · · · · · · · · · · · · · · · · · ·	
**Gladiolus ledoctei			**Diplolophium marthozianum		
Eriosema englerianum			 Iridaceae sp.2	· · · · · · · · · · · · · · · · · · ·	
Bulbostylis cupricola		•	Xerophyta equisetoides	•	
Ipomoea recta		•	*Haumaniastrum robertii	•	
Ocimum vanderystii			**Bulbostylis cupricola		•
Andropogon schirensis			Rendlia altera		
**Bulbostylis pseudoperennis	•	•	Buchnera randii		
Cyanotis longifolia		•	*Triumfetta welwitschii		
*Crotalaria cobalticola		•	Justicia elegantula		
*Haumaniastrum robertii	Group 3	•	Eriosema englerianum		
Eragrostis racemosa	Group 3	•	Euphorbia zambesiana	Group 3	
Sporobolus congoensis		•			
			**Bulbostylis pseudoperennis		

Linear regression between tolerance (amplitude) and optima along cobalt gradient for all species (grey) and group 2 (orange). Regressions are not significant (P>0.05).

Representation of the ecological realized niches for copper (left) and cobalt factors (right) of 80 metallophyte species. Classification has been performed according to the optimum positions along the metal gradient. * strict endemic, ** broad endemic.

Conclusion

The optima of Katangan metallophytes are distributed over the whole Co gradient. Along the Cu gradient, there is a gap of 4000 ppm between group 2 and 3.

The same groups for Cu and Co gradient do not necessarily contain the same species.

The large amplitude of species typical of highest Cu concentrations (Group 3) indicates that their optimal position on the hill is not related to a physiological requirement. These species have most probably their optima in areas with low competition.