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June 26–30, 2013, Tartu, Estonia

Plant ecological niche distribution along heavy metal gradients

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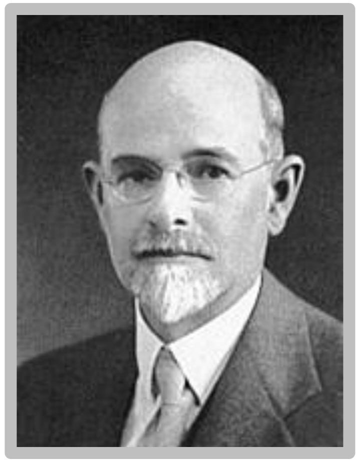
Ecological niche

- Place occupied by an organism in ecosystem (Grinnell, 1917)
  - Sum of conditions that allow an organism to occur in environment



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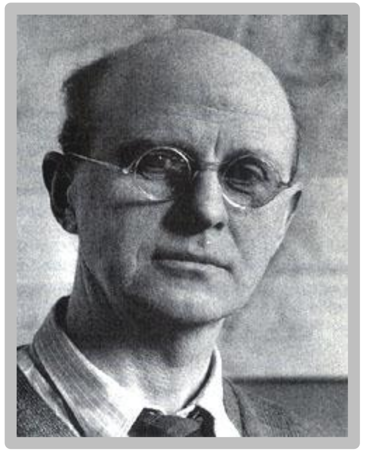
- Role of an organism in ecosystem (Elton, 1927)
  - Influence a an organism on his environment



Ecological niche

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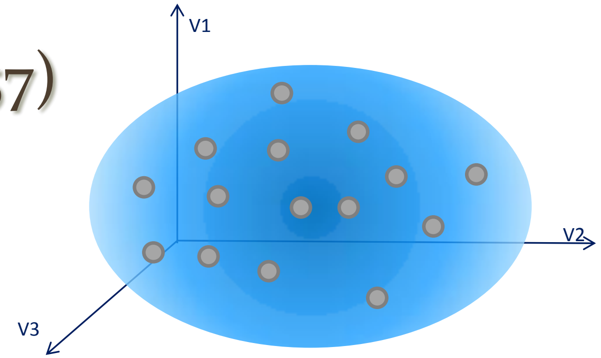
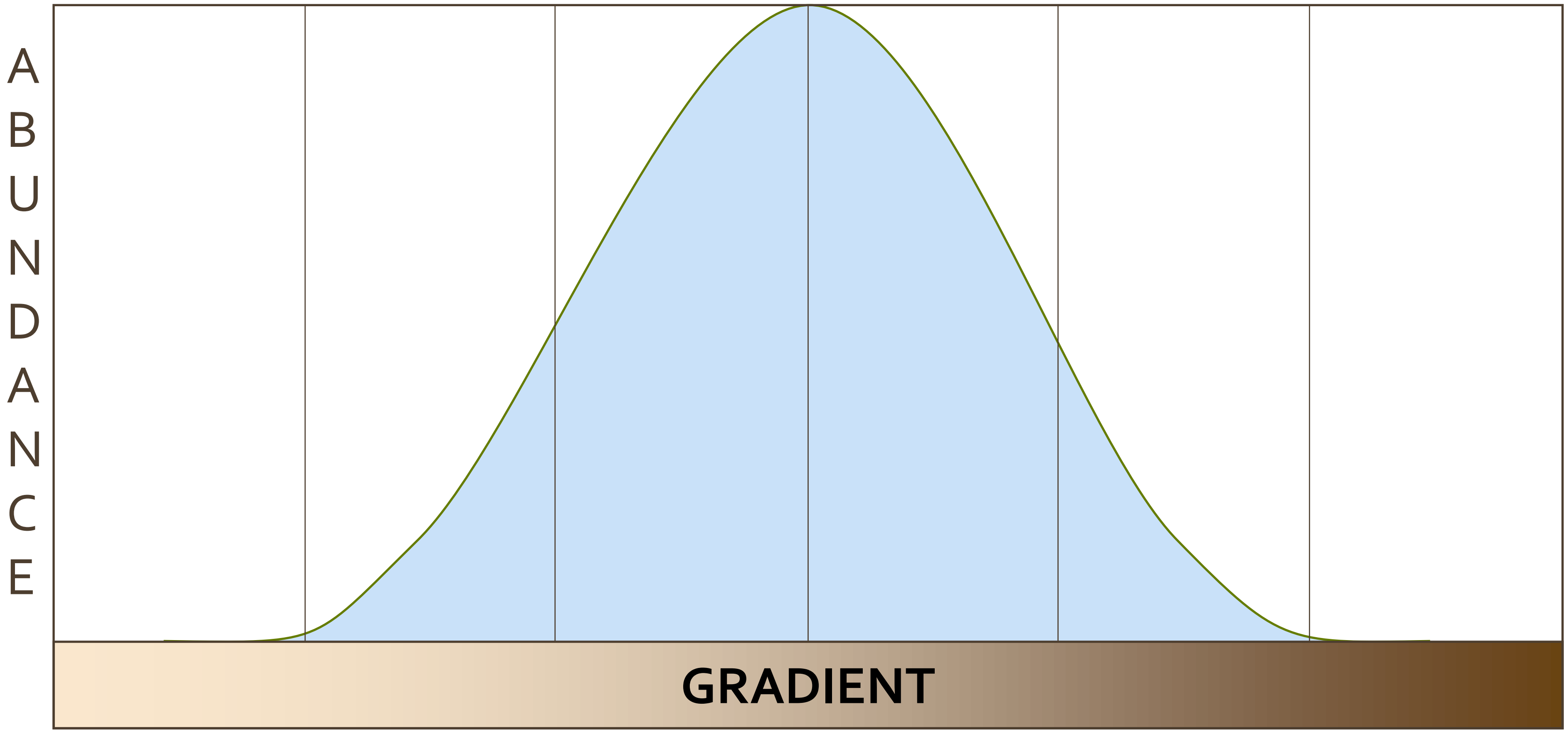
  - Sum of conditions that allow an organism to occur in environment
- Role of an organism in ecosystem (Elton, 1927)
  - Influence a an organism on his environment
- n-dimensional hypervolume (Hutchinson, 1957)
  - Dimensions = conditions and resources



3-dimensions niche (V)

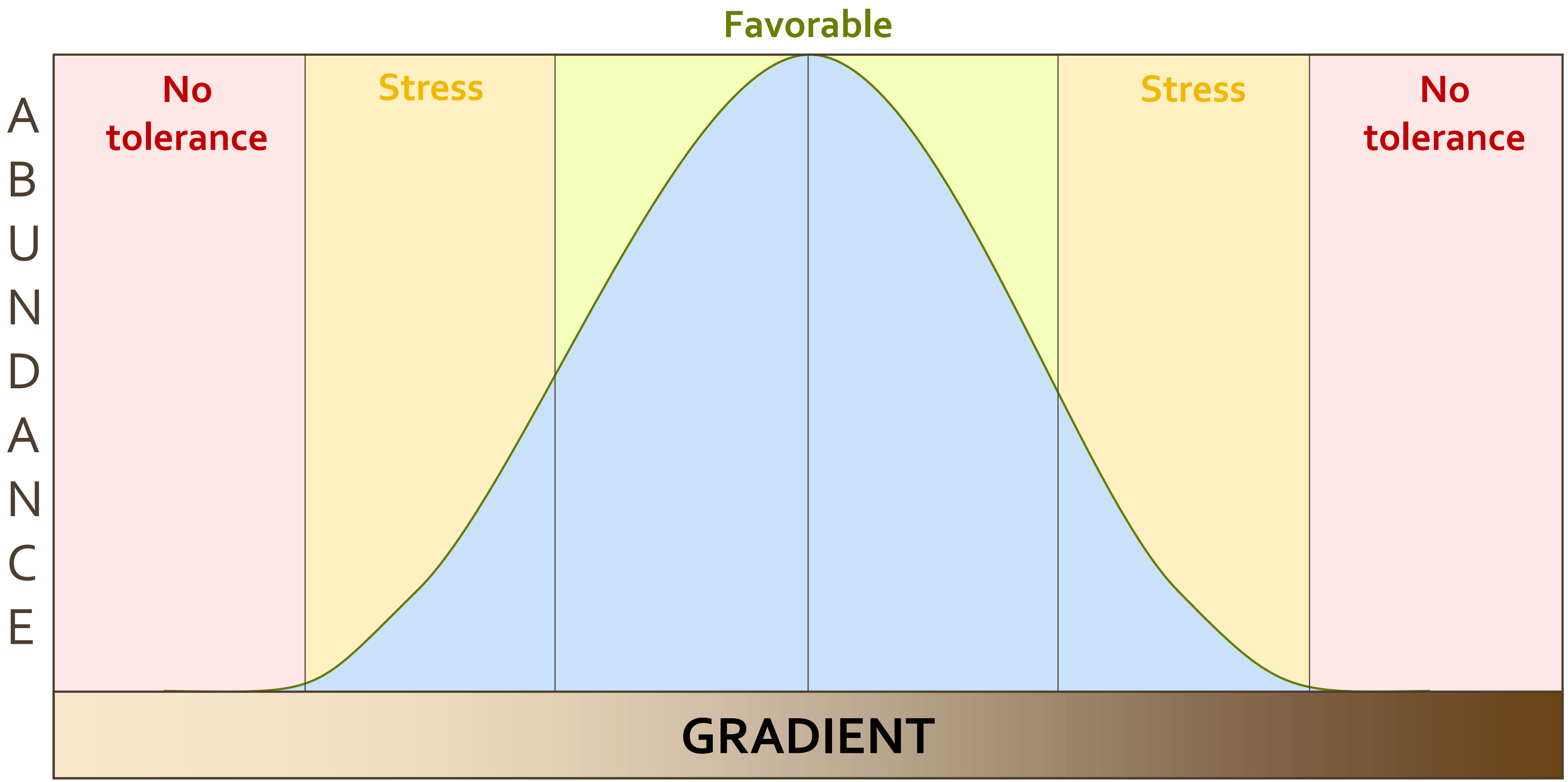
Ecological niche

- For one environmental factor



Ecological niche

- For one environmental factor



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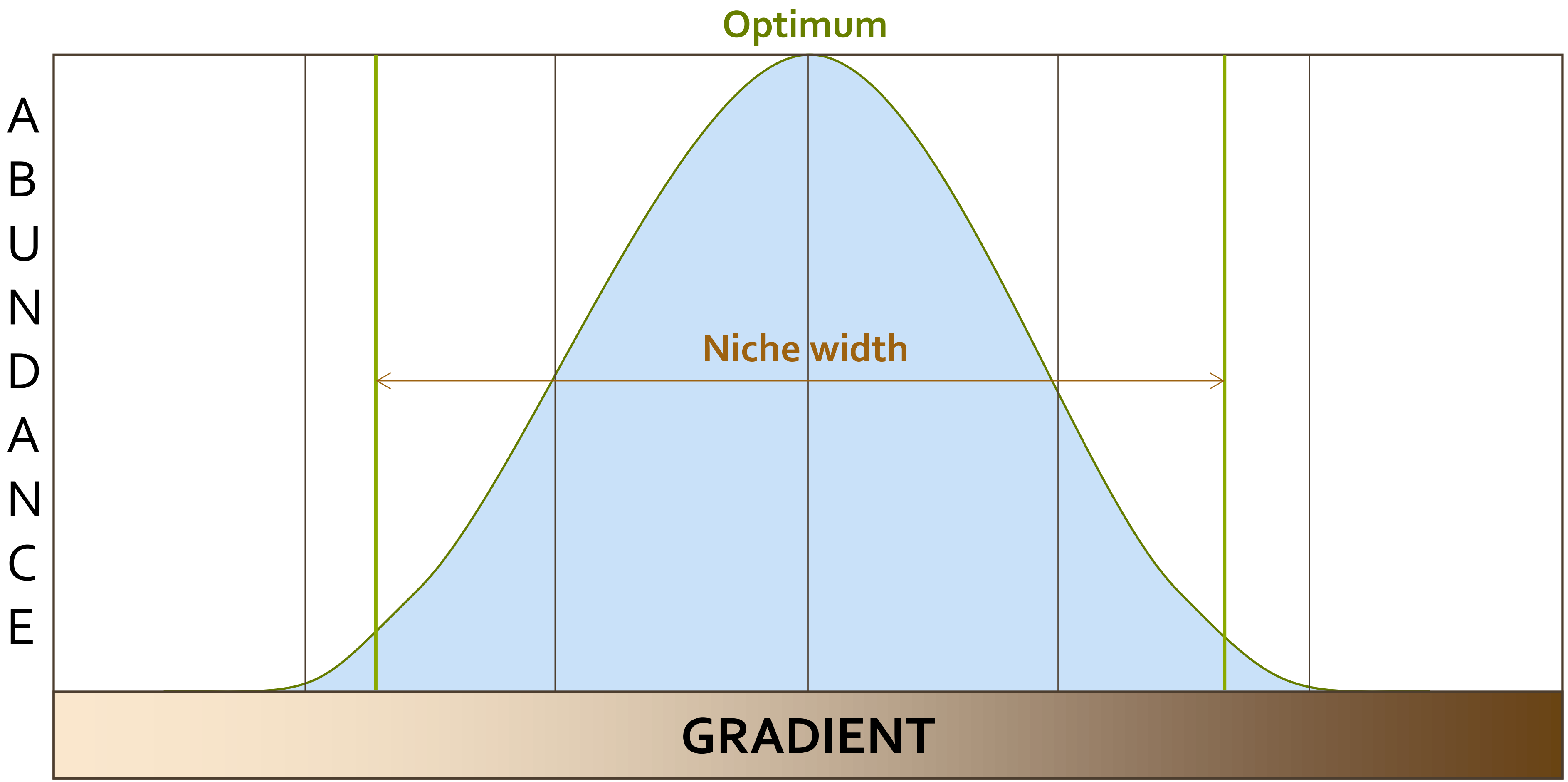
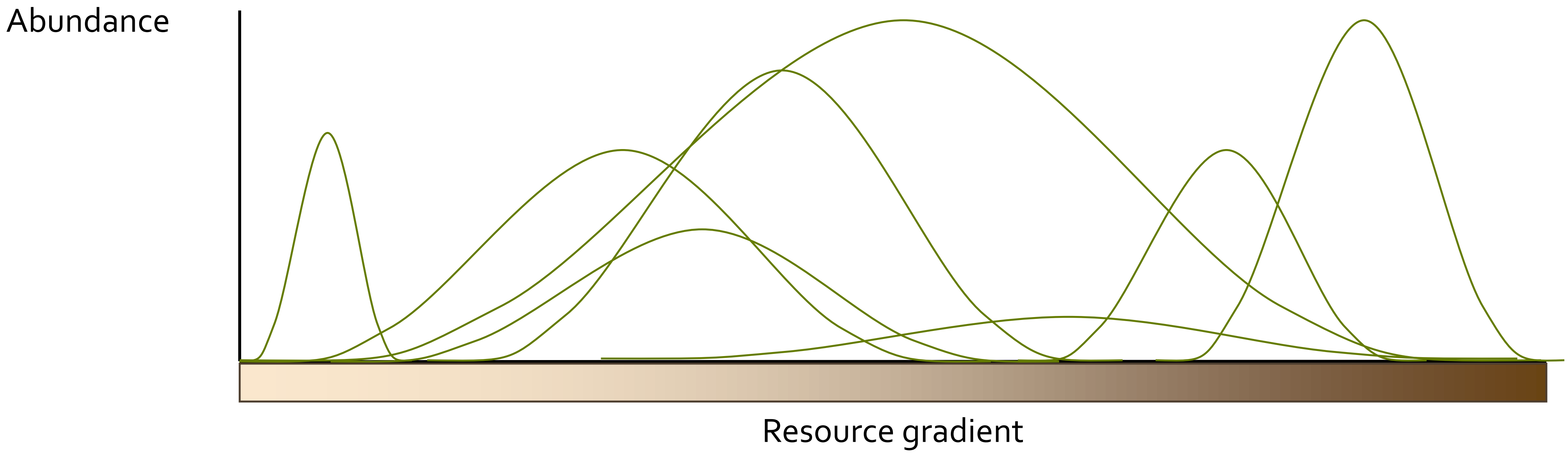


Species distribution

- Individualistic continuum concept (Gleason, 1926)

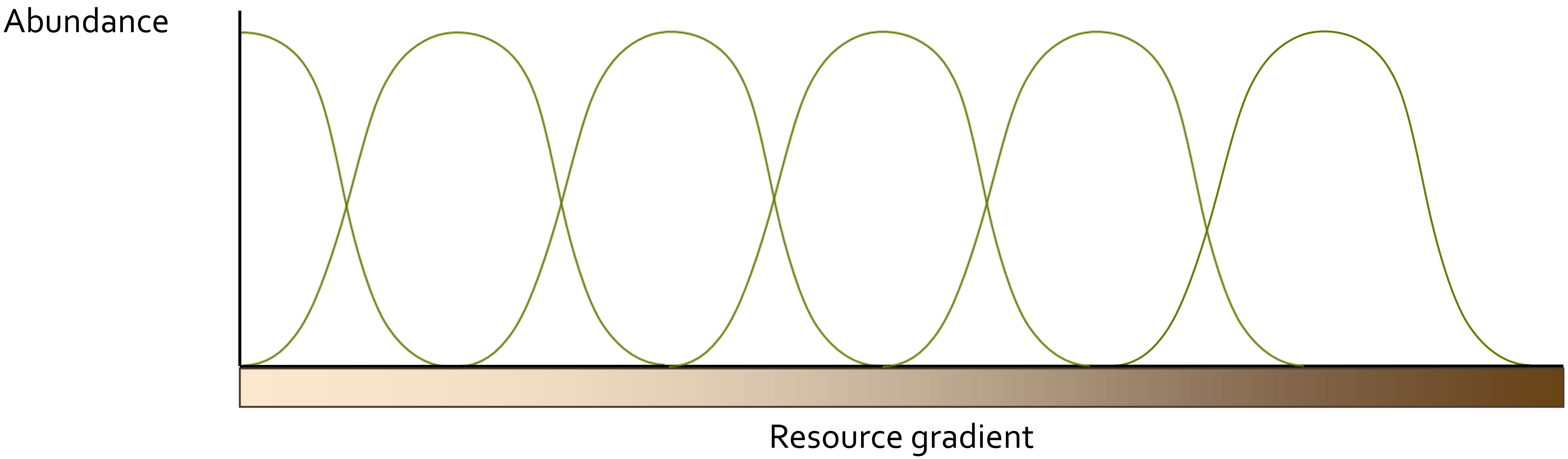
  Species response assemblages are random in community



Species distribution

- Resource partitioned continuum (Austin, 1985)

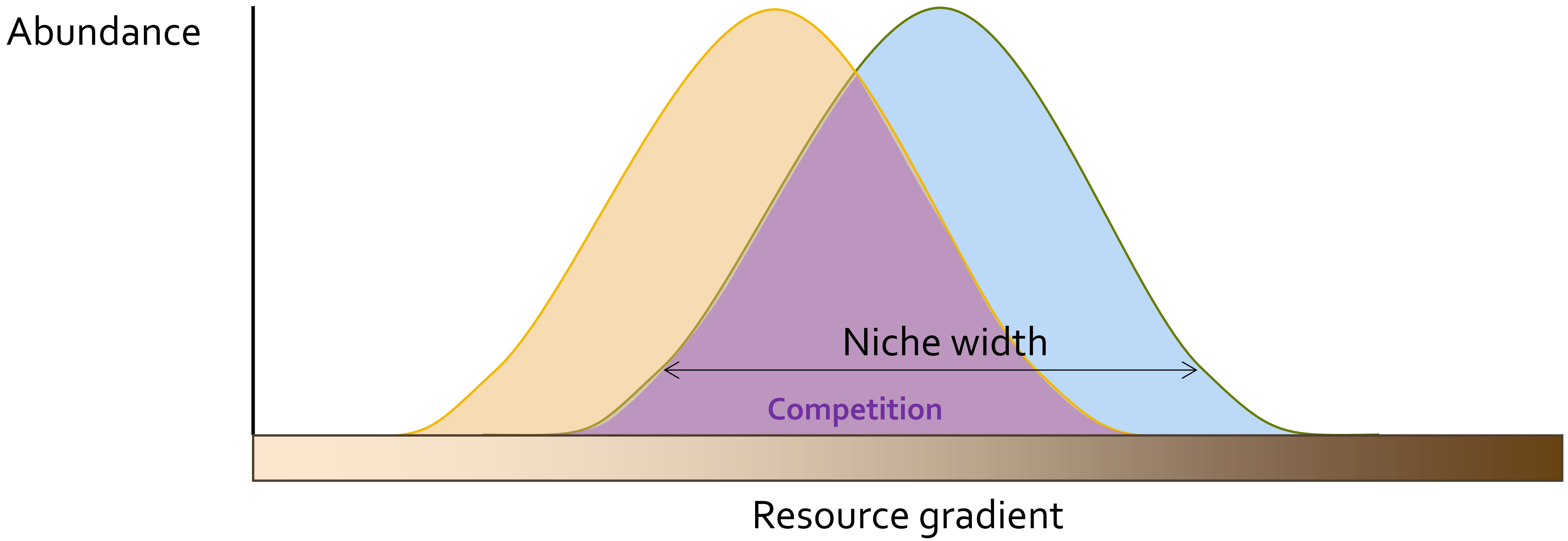
  Resource partitioning and competition lead to uniform distribution along gradient



Species distribution

- Competitive exclusion principle (Gause, 1934)

  Two species competing for the same resources (niche) cannot coexist if other ecological factors are constant



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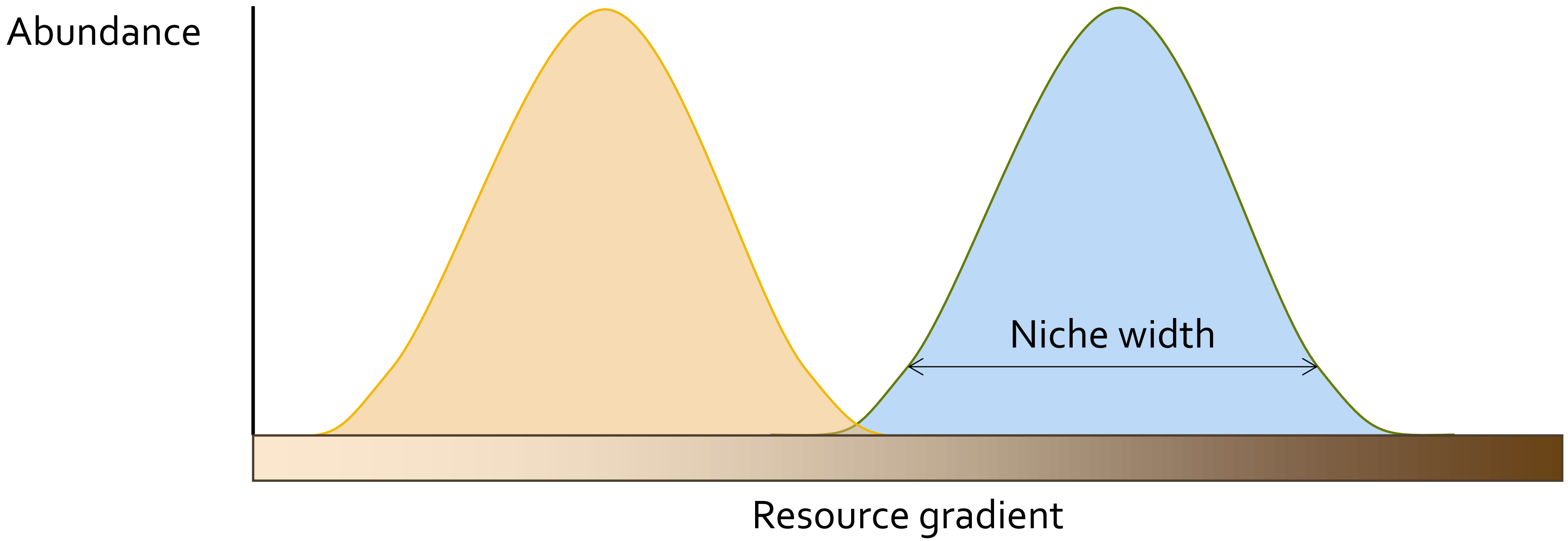
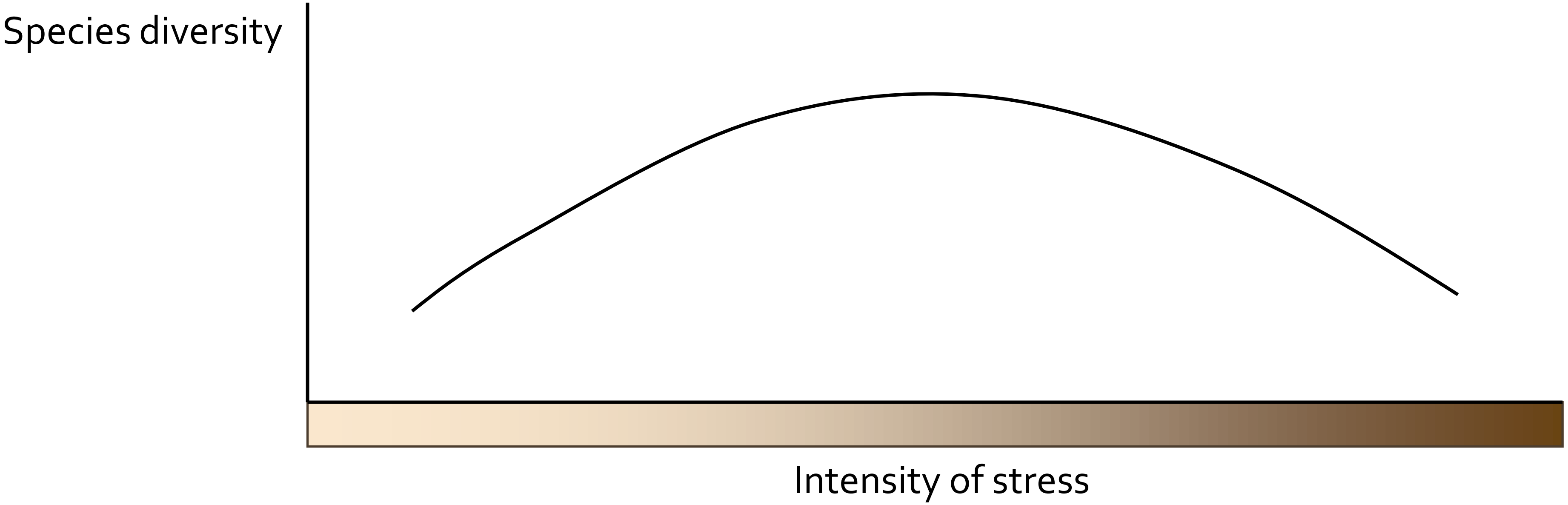


Species distribution

- Competitive exclusion in herbaceous vegetation (Grime, 1973)

Species diversity is higher at intermediate intensity of stress



Species distribution

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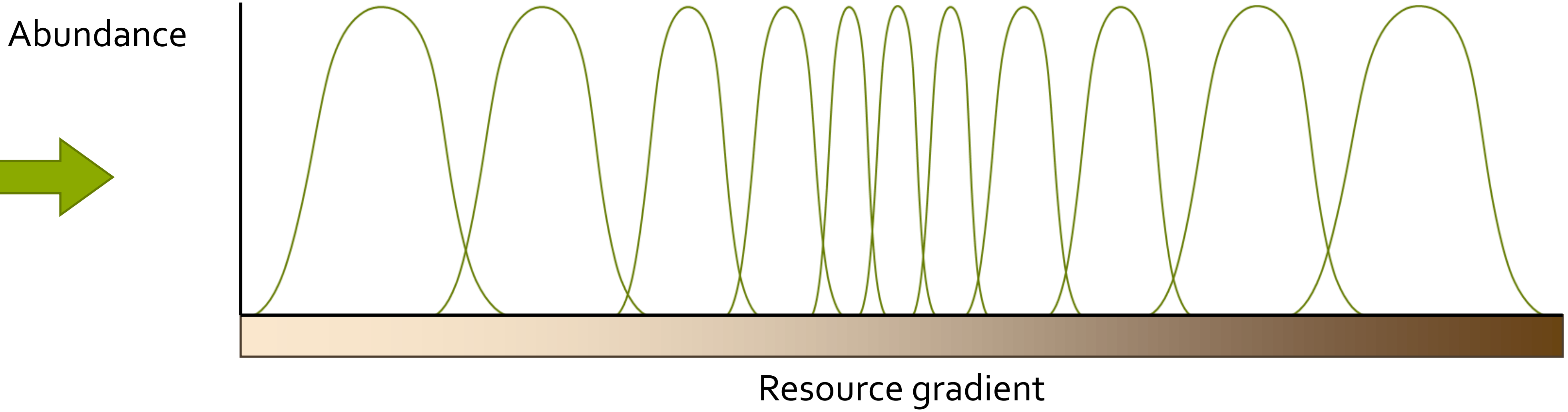
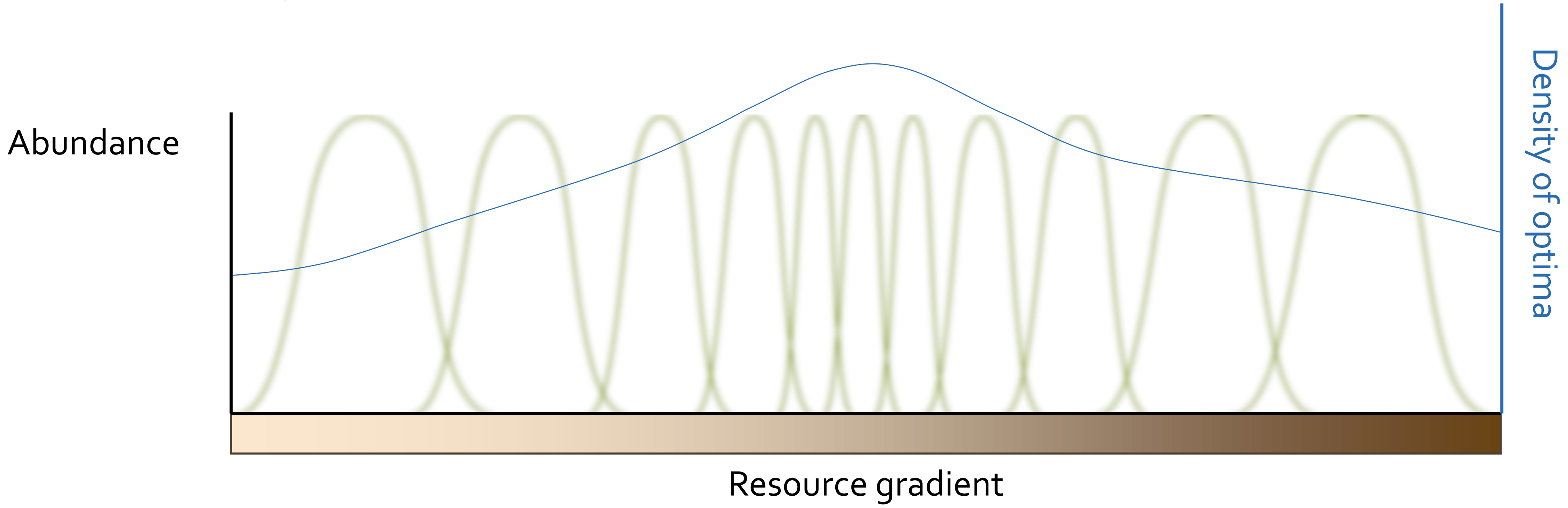


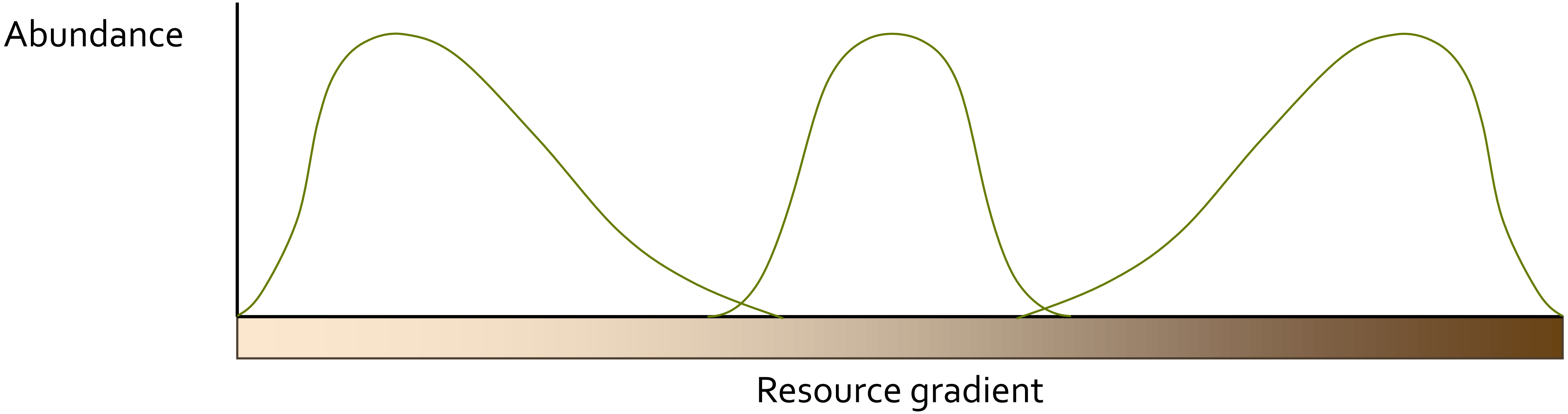
Species distribution

- Plant species are packed on mesic position of environmental gradient ;
- Niche widths are narrower when optima of species are packed (Lawesson & Oksanen 2002)



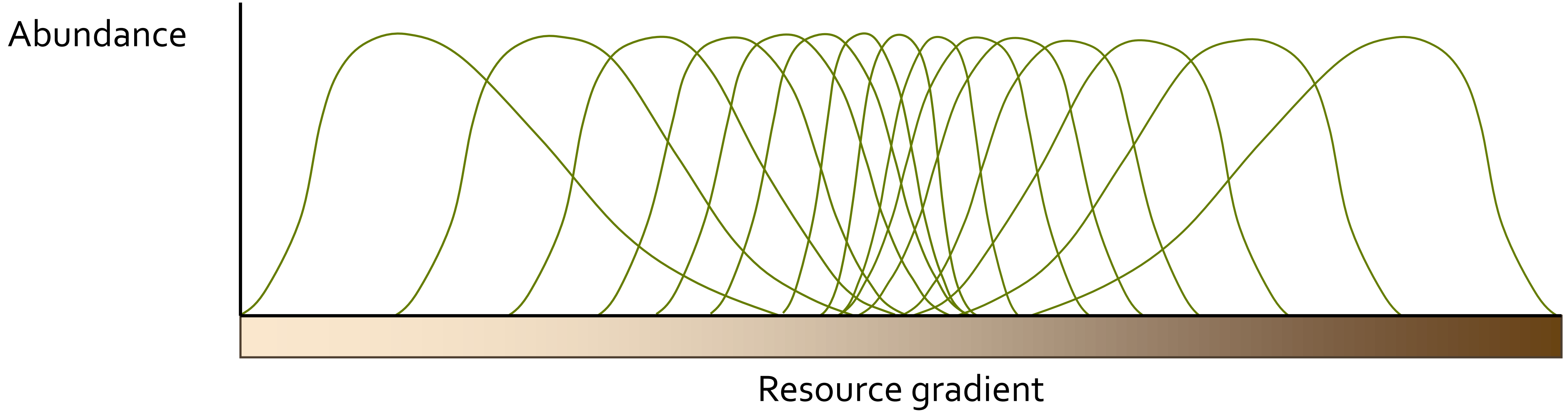
Species distribution

- Ecological response curves are often skewed …
- …with a 'longer tail' towards mesic position (Austin & Gaywood, 1994)



How coexist species in community along resource gradient ?

- Species optima are packed on mesic position
- Species tolerances are narrower in mesic conditions
- Response curves are more skewed at the extremities of gradients



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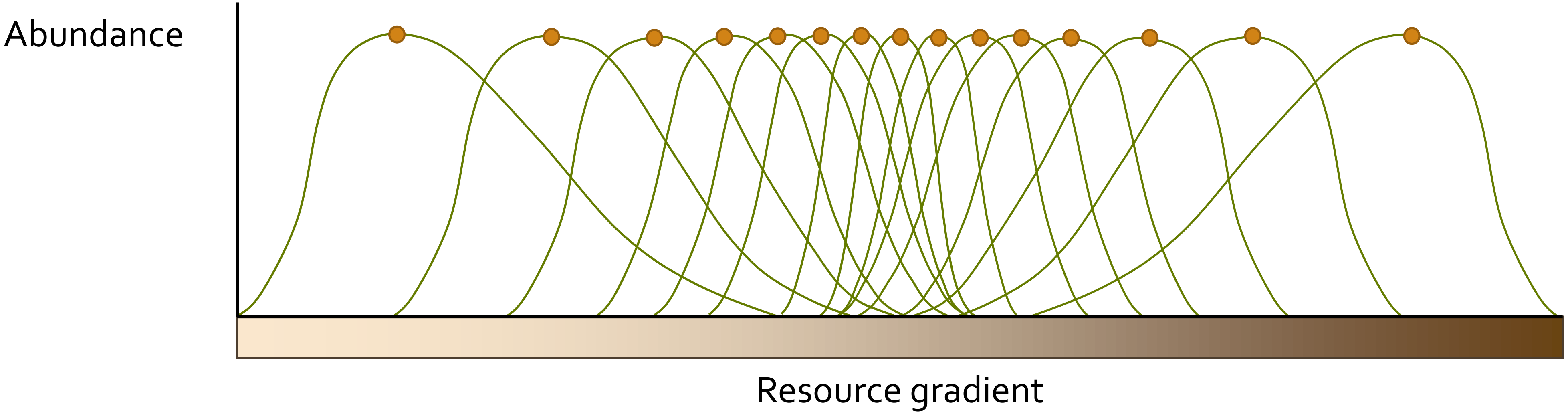

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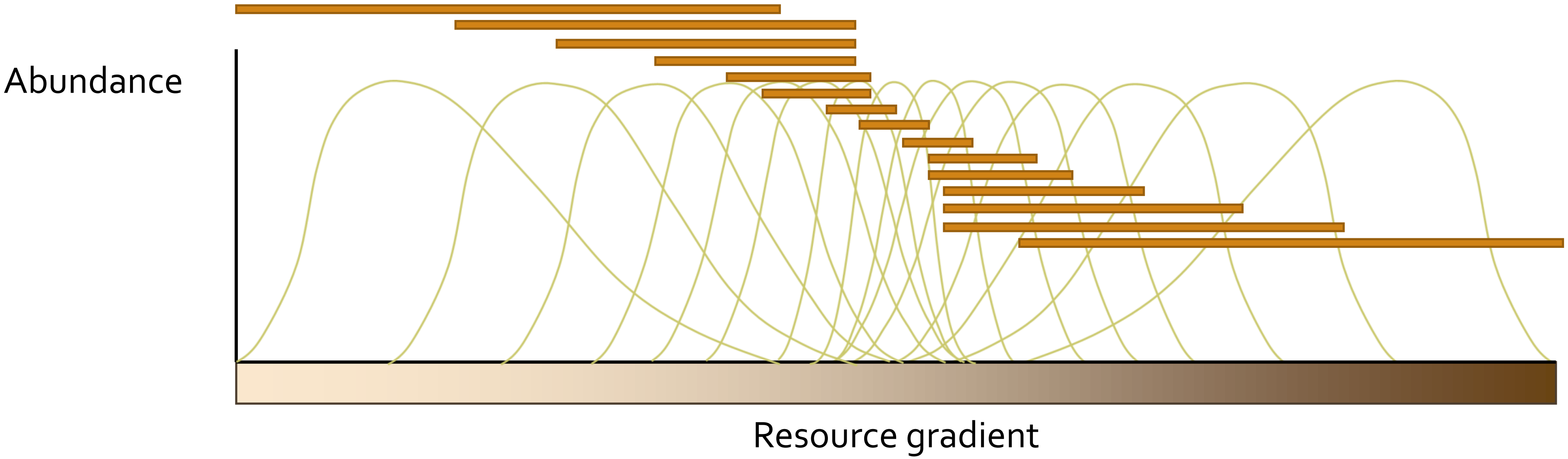

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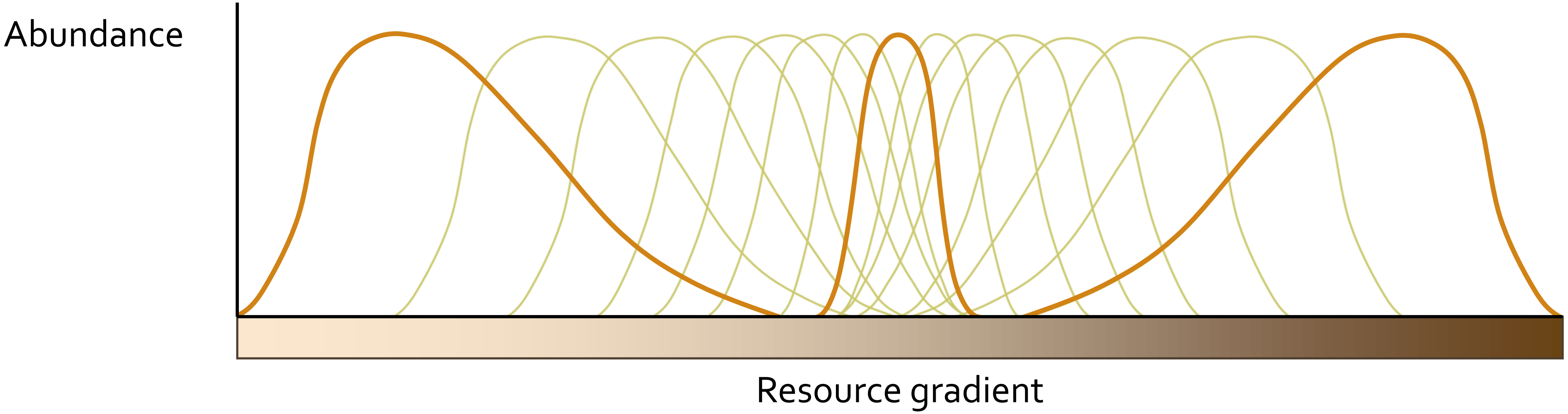

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In this study,
we tested these assumptions on response curves
along a **metal toxicity gradient**

Resource gradient

Resource gradient vs metal toxicity gradient

Resource gradient vs metal toxicity gradient

Most studies focus on macronutrients = low toxicity

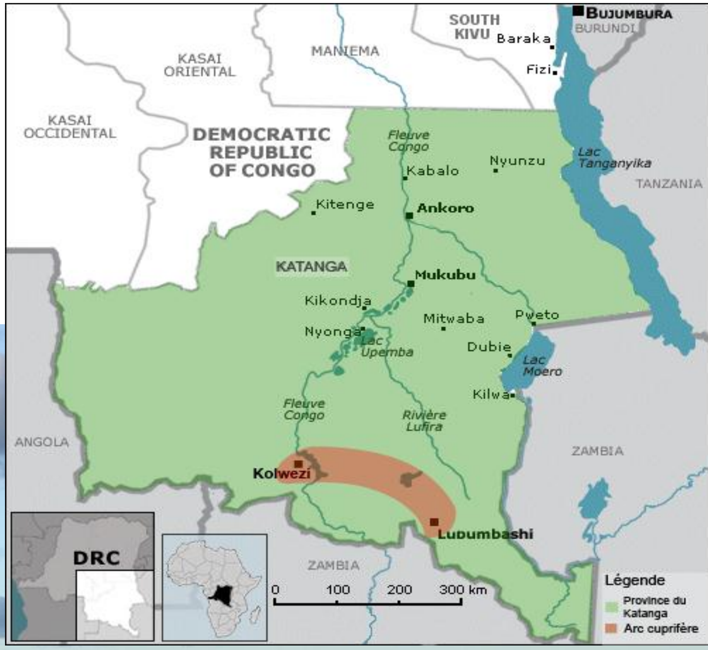
Resource gradient vs metal toxicity gradient

Species distribution on Cu, Co, Pb, etc. ?

Metals are toxic at lower concentrations

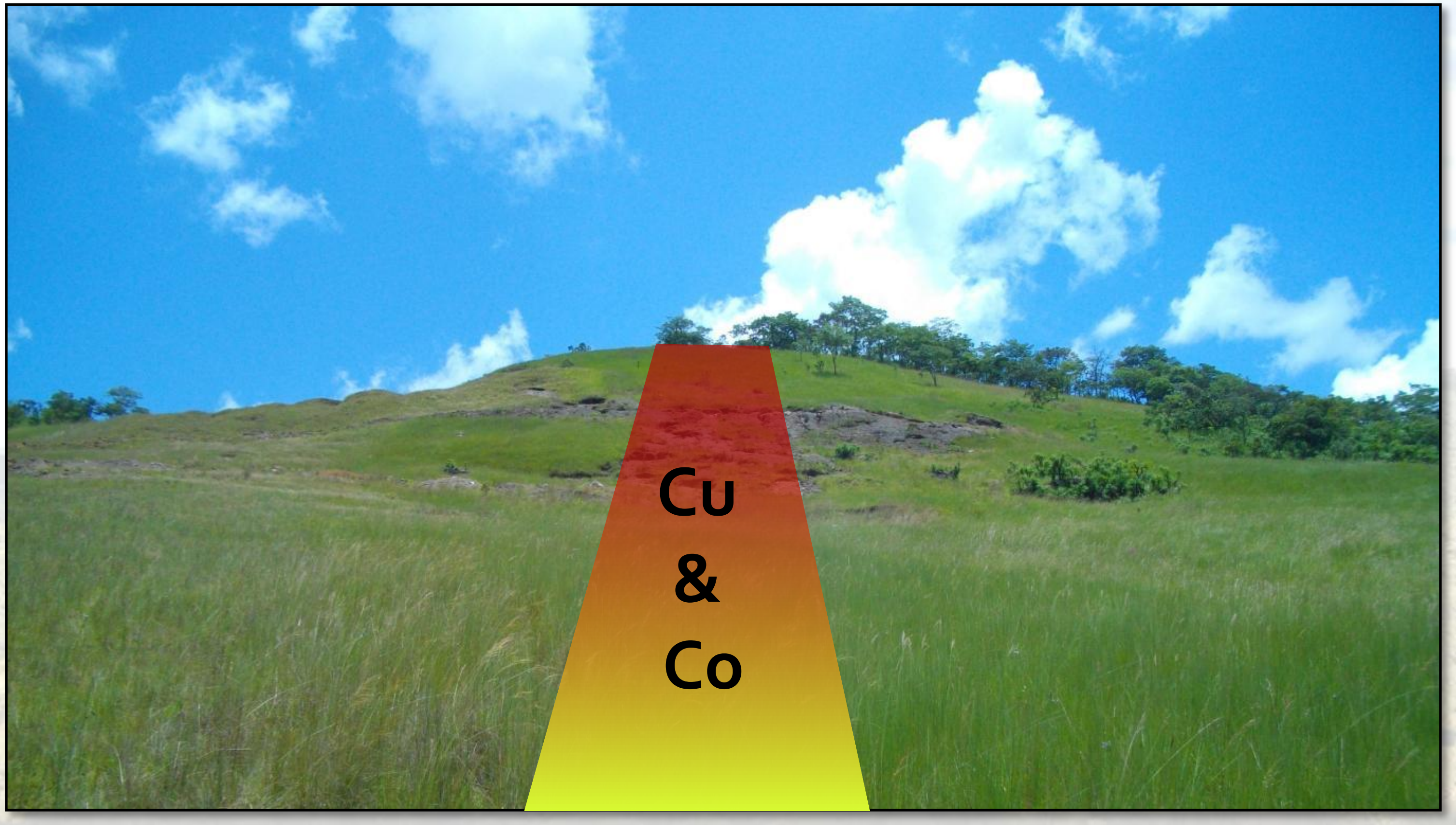
Study site

- Katangan copperbelt, Katanga (D.R. Congo)
- Copper and cobalt outcrops → contaminated soils



Original flora

- More than 650 plant species, 9 % endemics



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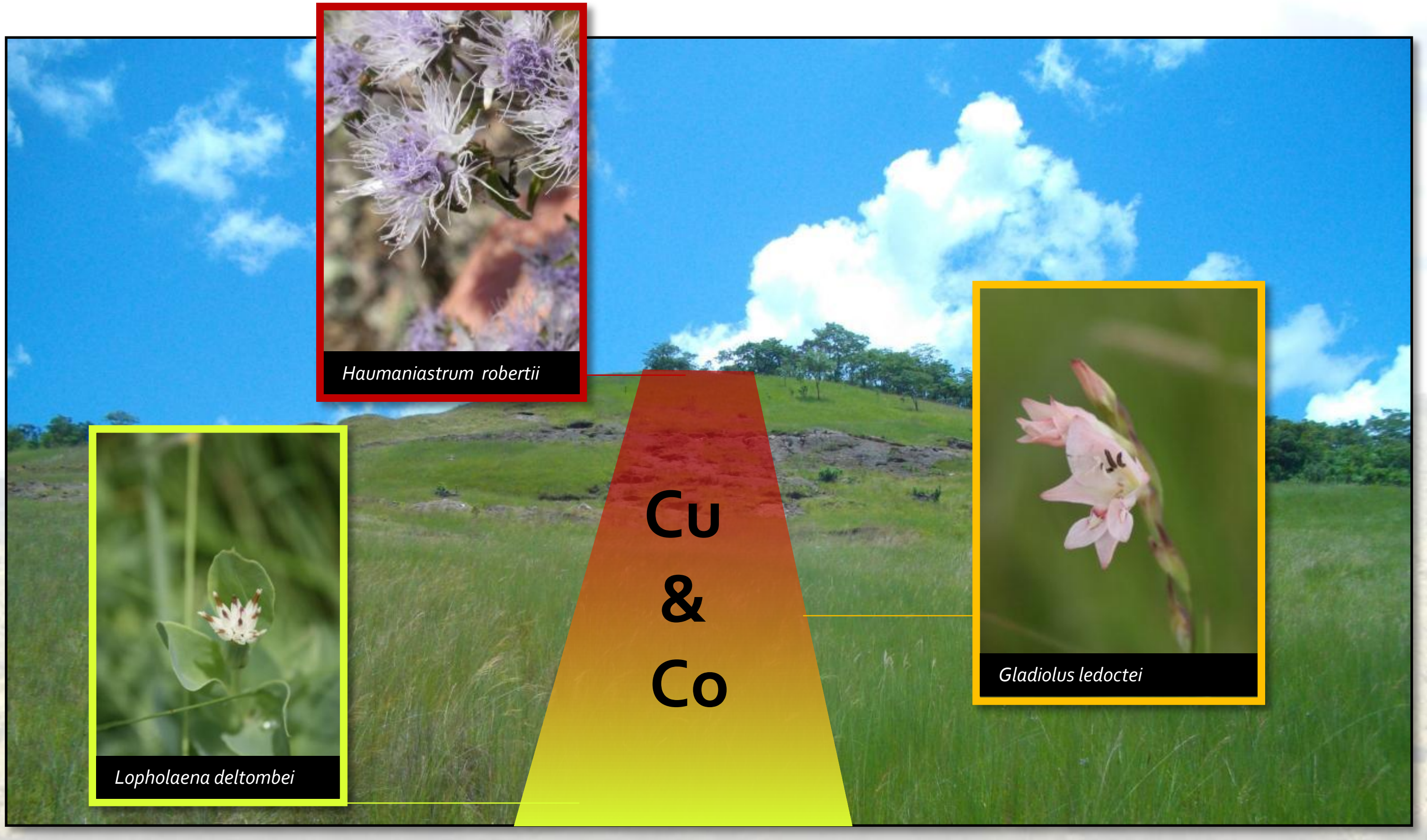
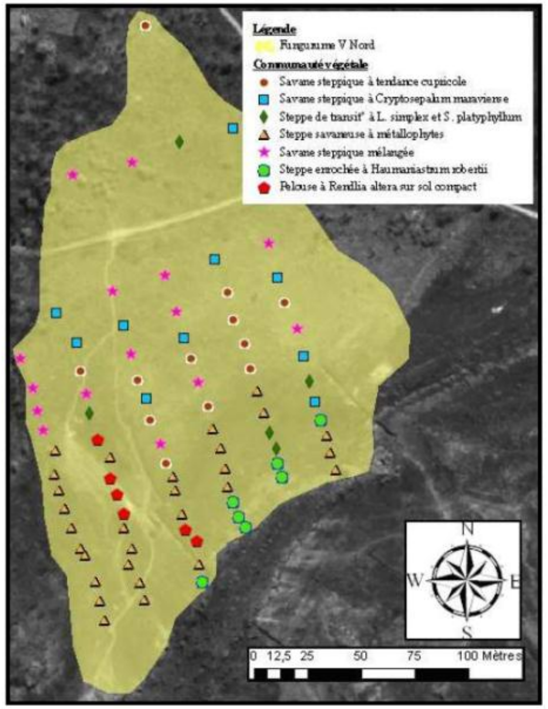


Sampling

- Vegetation
  - 184 taxa
  - 172 quadrats (1m²) on 3 hills
    - Presence/absence



Example on one hill

- Soils
  - 10-15 cm depth
  - Cu and Co extracted by EDTA 4.65 (atomic absorption spectroscopy)

Modeling & analysis

- Select taxa with occurrence ≥ 8 in dataset (=80 taxa)

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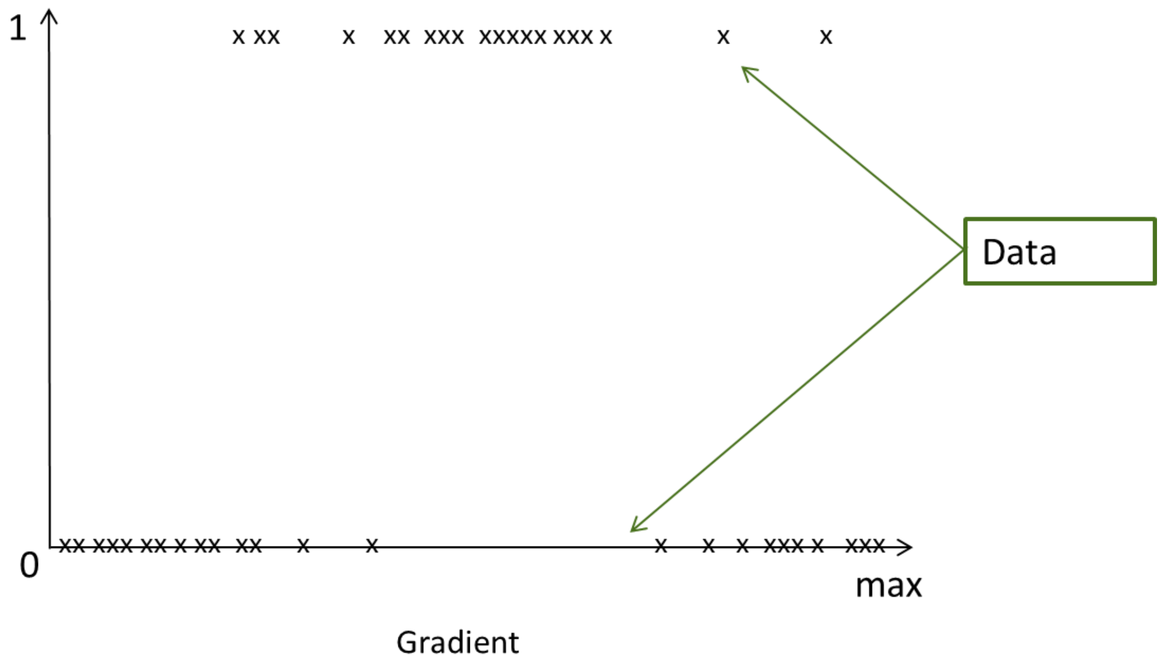
  - Non parametric method, robust
  - Logistic approach (0/1)



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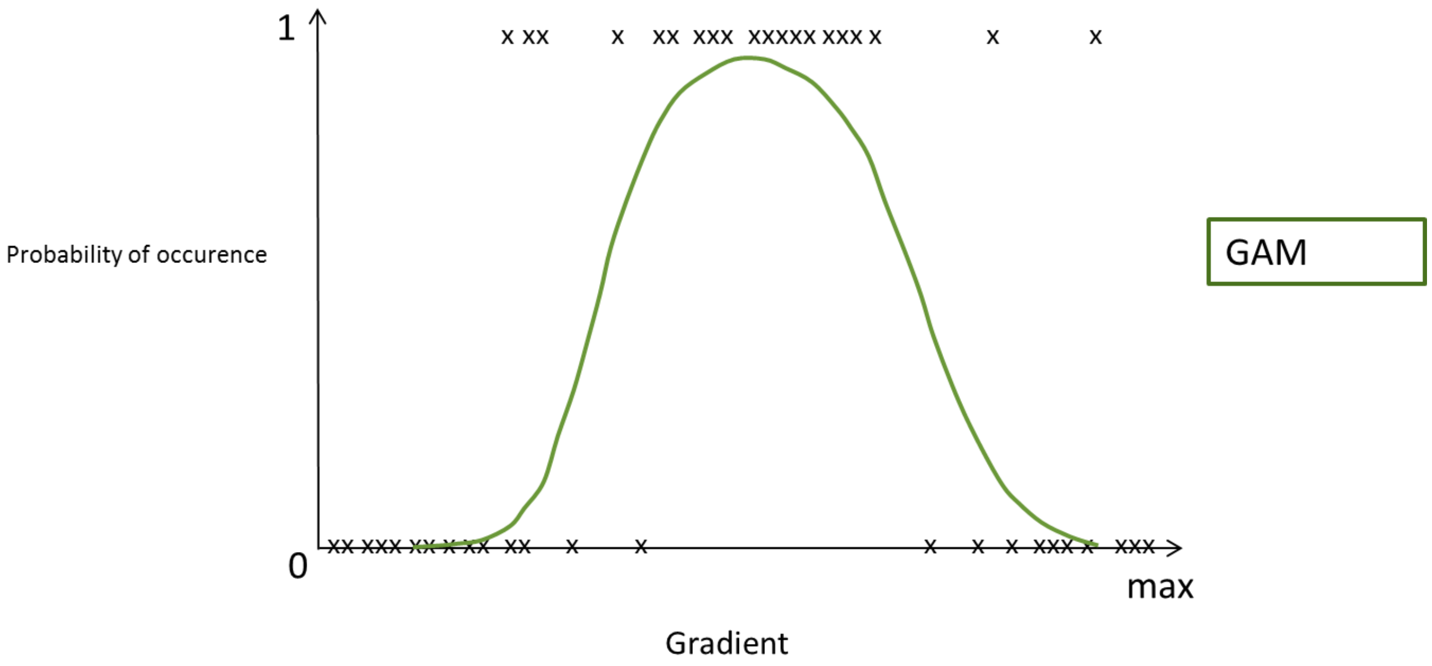
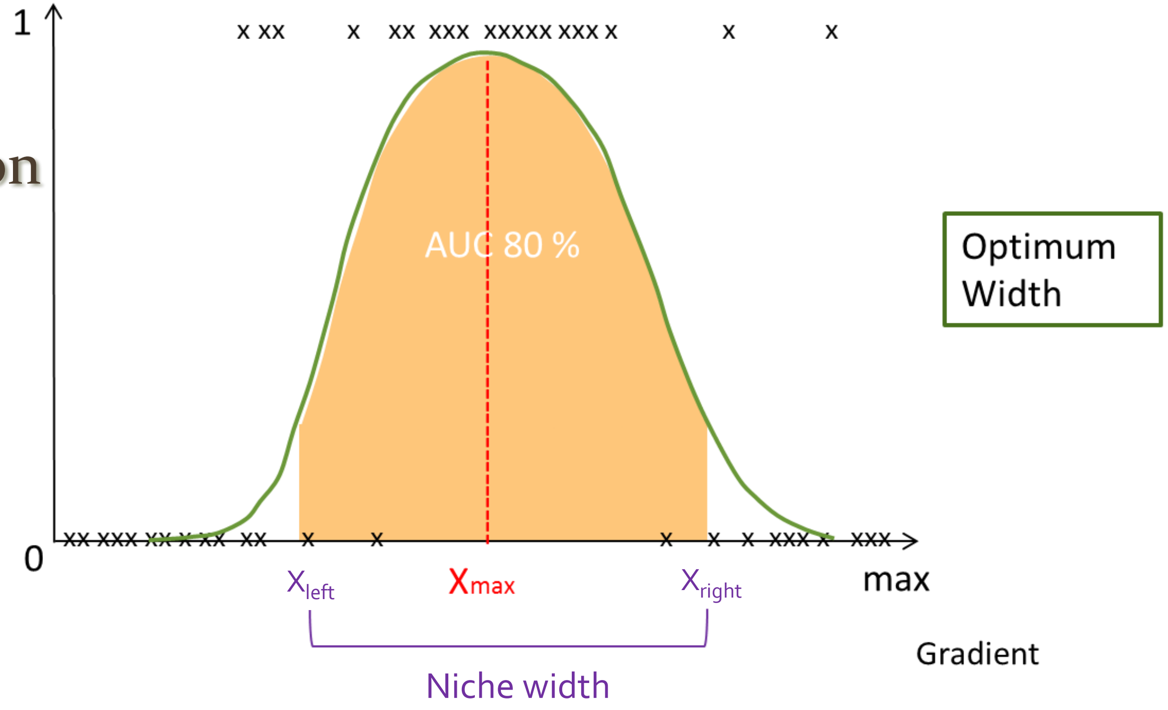


Modeling & analysis

- Select taxa with occurrence ≥ 8 in dataset (=80 taxa)
- Generalized additive model (Cu and Co) (Hastie & Tibshirani, 1990)
  - Non parametric method, robust
  - Logistic approach (0/1)
- Niche optima and niche width calculation
  - Optimum : X location for Y-max
  - Width : extremities of AUC 80 %

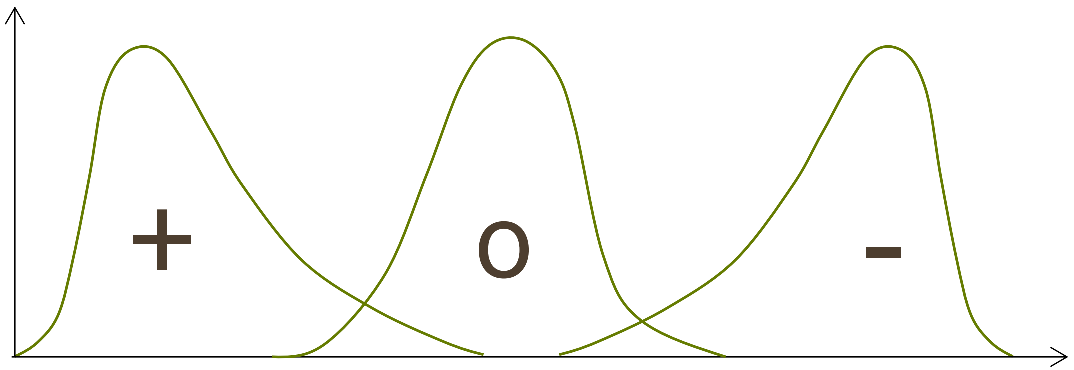


Modeling & analysis

- Skewness coefficient (Fisher, 1930)

$$\mu_3/\sigma^3$$

  - μ3, central moment of order 3
  - σ, standard deviation ($\mu_2^{1/2}$)



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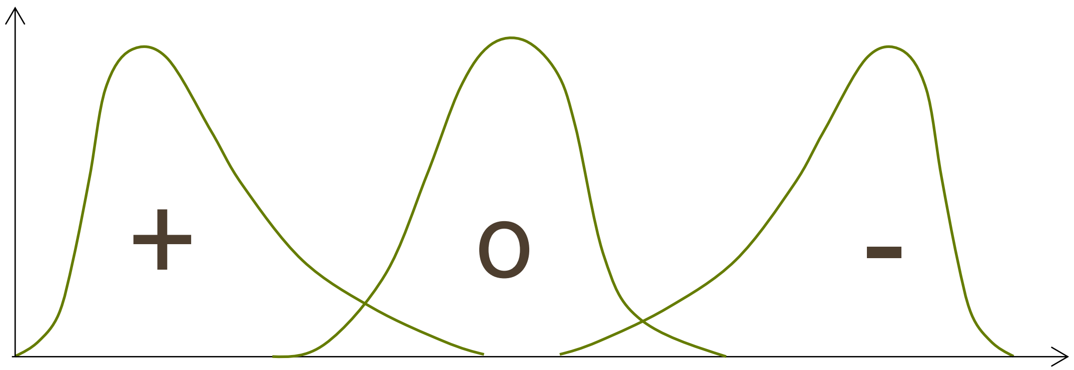


  - μ3, central moment of order 3
  - σ, standard deviation ($\mu 2^{1/2}$)

- Density curve
  - Kernel density

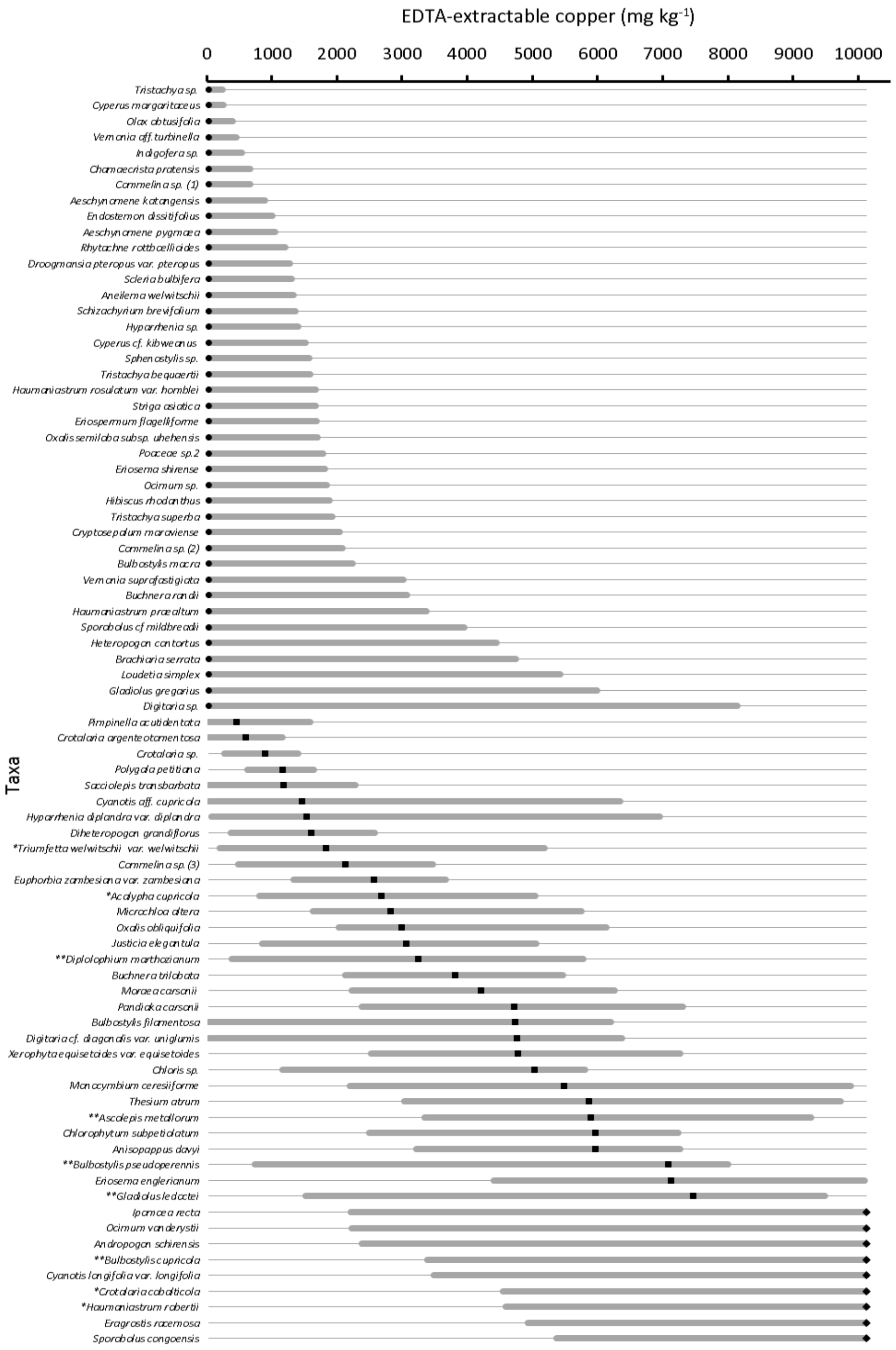
Taxa distribution

Along copper gradient

Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil $^{-1}$



= niche optima
= niche width

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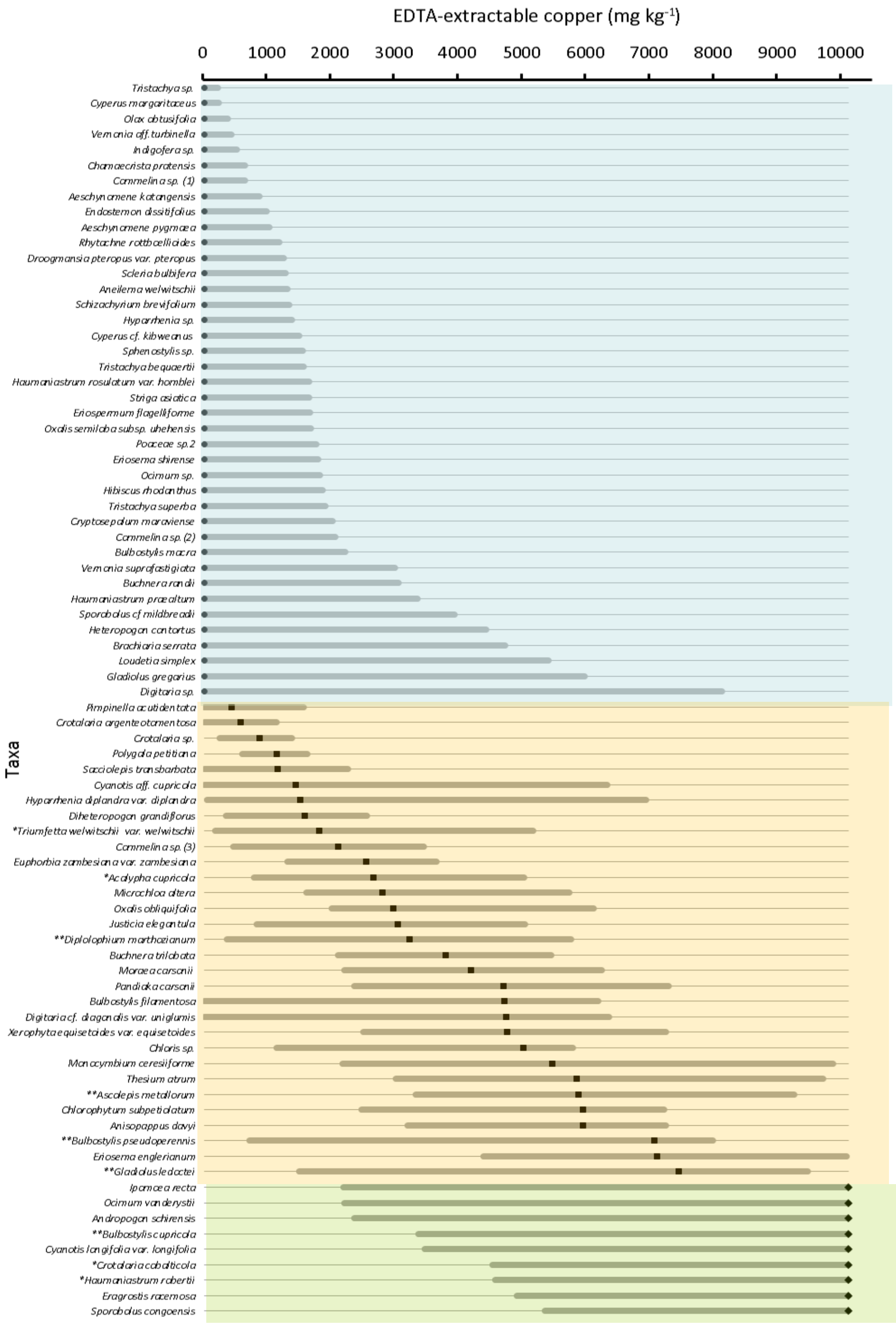

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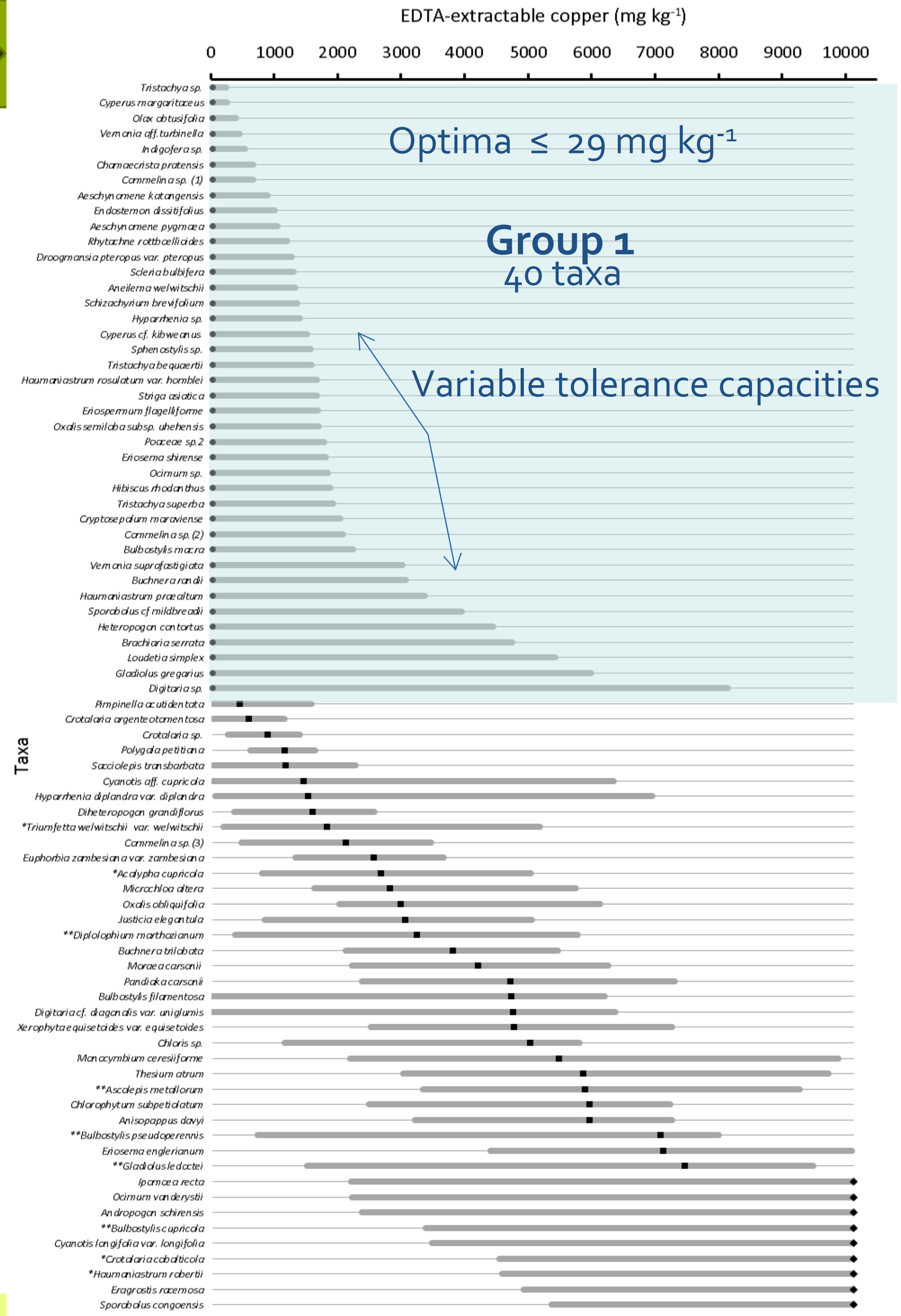
Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil $^{-1}$
- Group 1 : 40 taxa



● = niche optima
▬ = niche width

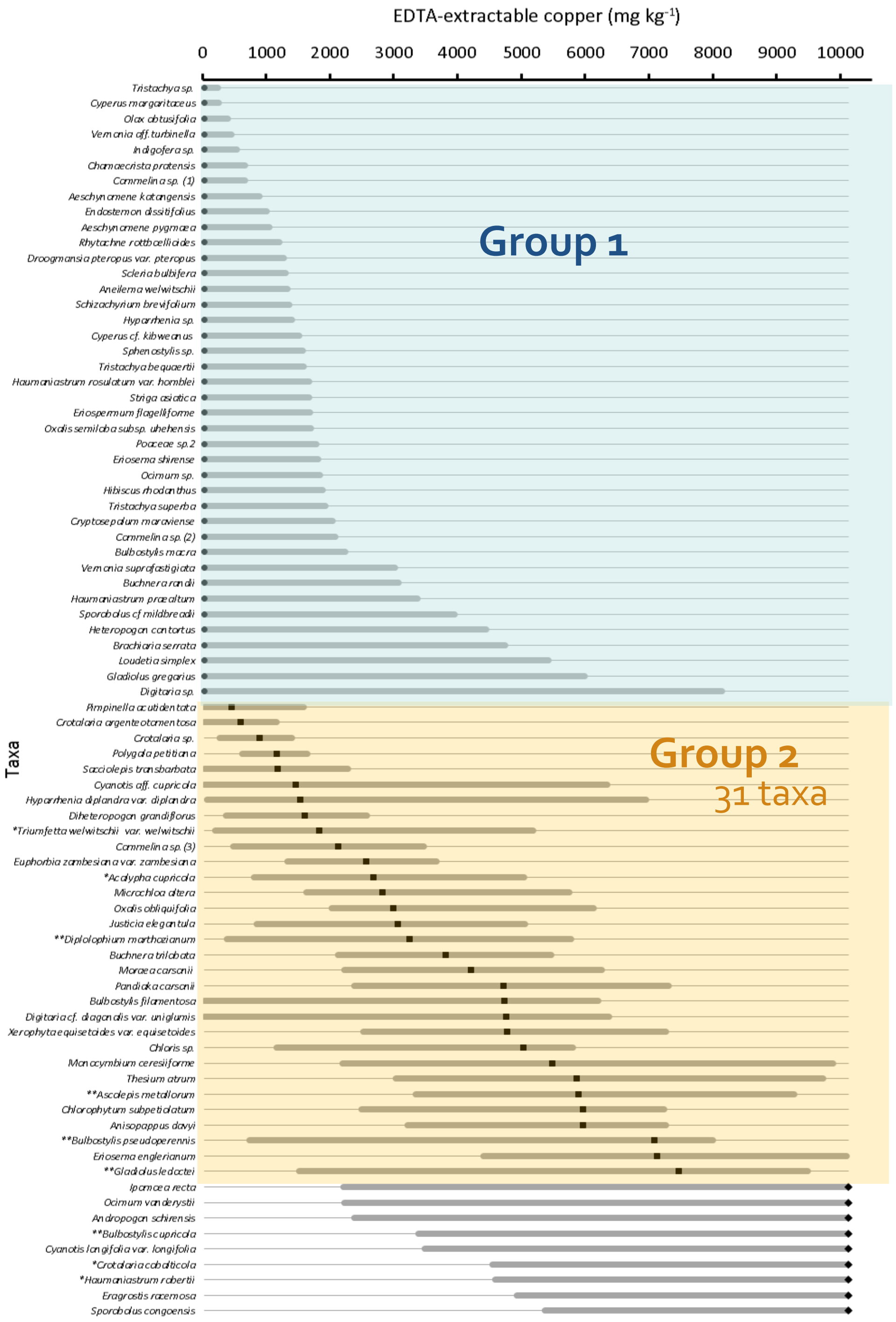
Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil $^{-1}$
- Group 1 : 40 taxa
- Group 2 : 31 taxa

Well defined and uniformly distributed optima

= niche optima
= niche width



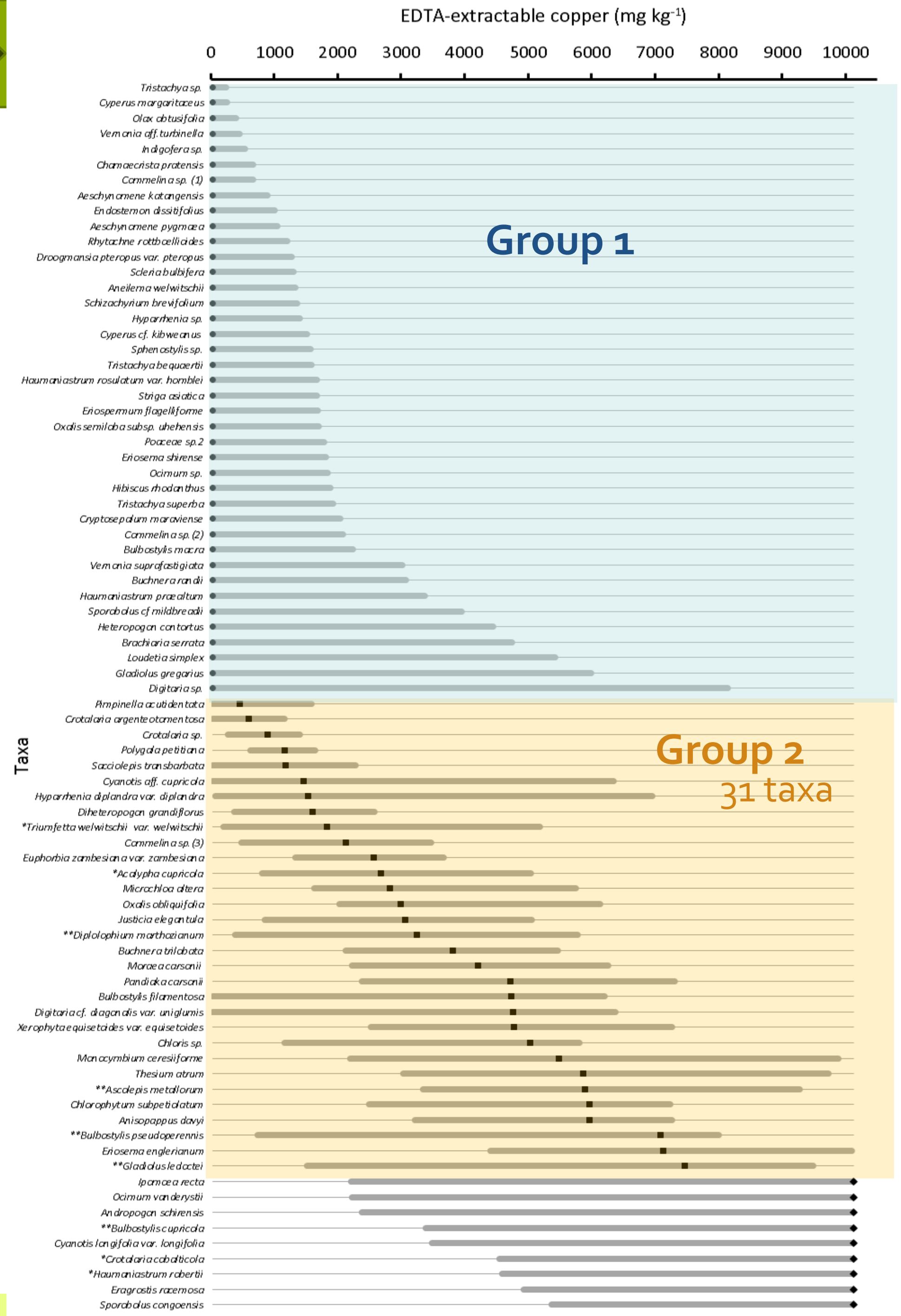
Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil $^{-1}$
- Group 1 : 40 taxa
- Group 2 : 31 taxa

Well defined and uniformly distributed optima

- Variable tolerance



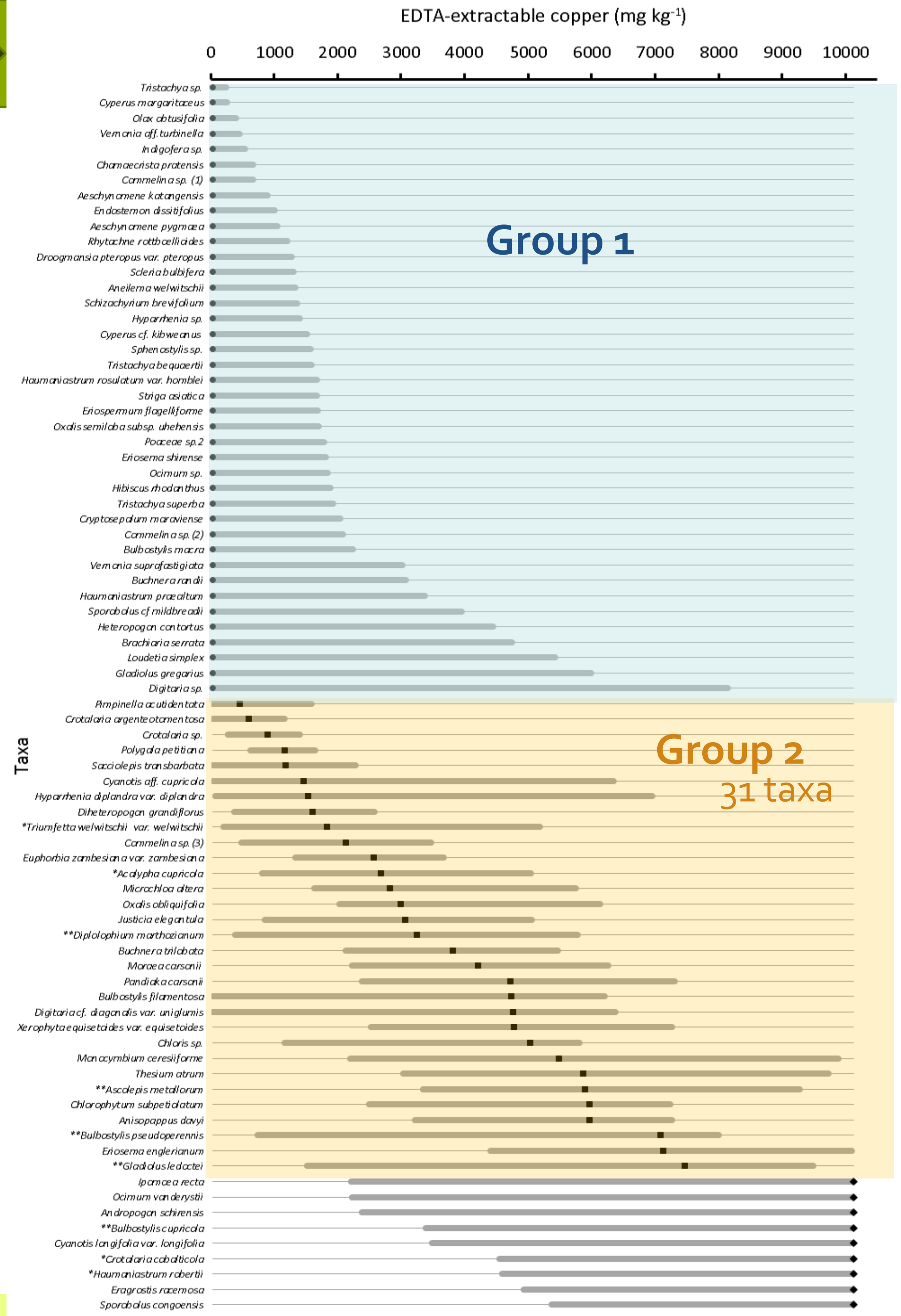
● = niche optima
▬ = niche width

Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil [-1]
- Group 1 : 40 taxa
- Group 2 : 31 taxa

Well defined and uniformly distributed optima
- Variable tolerance
- Competition



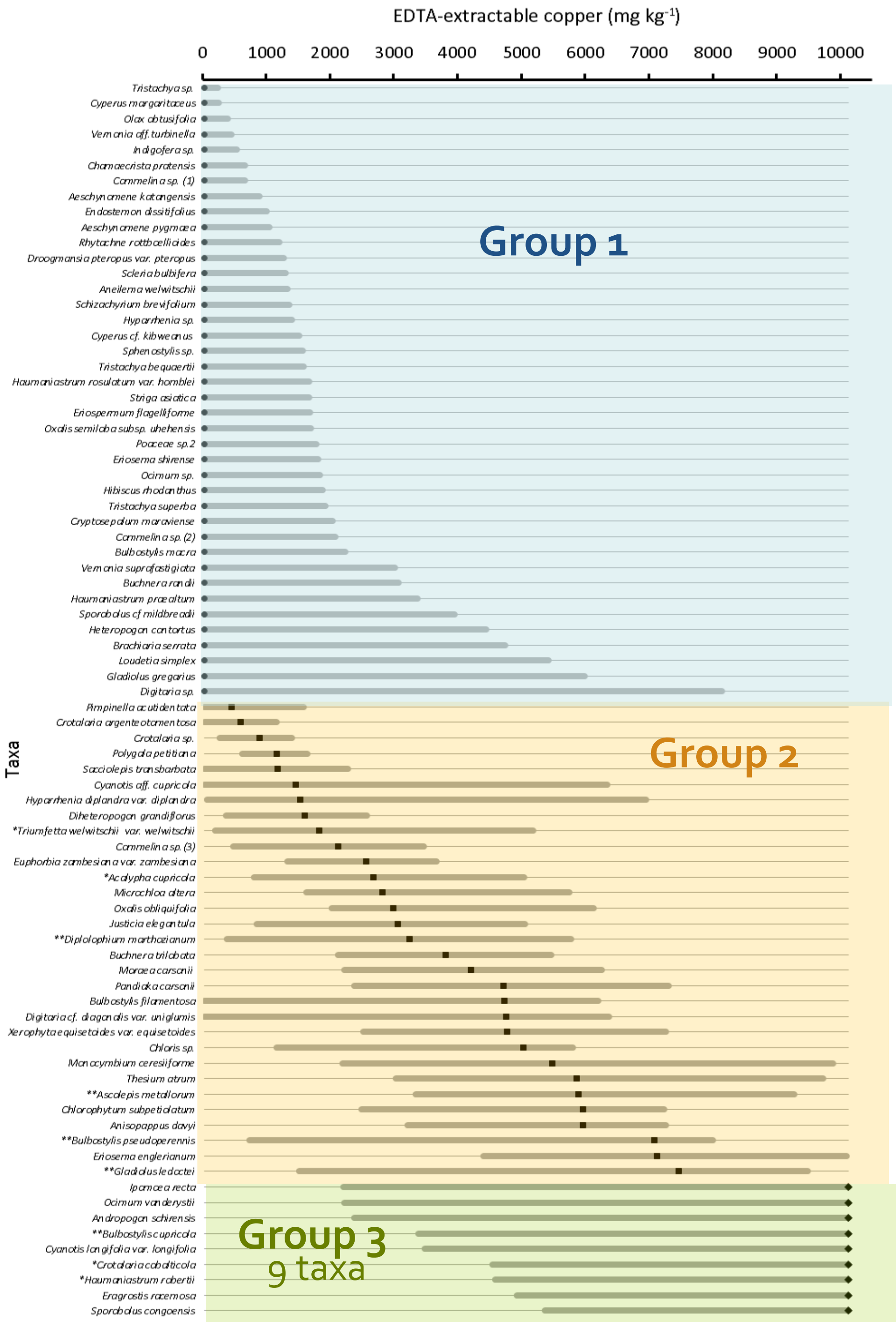
● = niche optima
▬ = niche width

Taxa distribution

Along copper gradient

- Range : 29 – 10 000 mg Cu.kg soil $^{-1}$
- Group 1 : 40 taxa
- Group 2 : 31 taxa
- Group 3 : 9 taxa

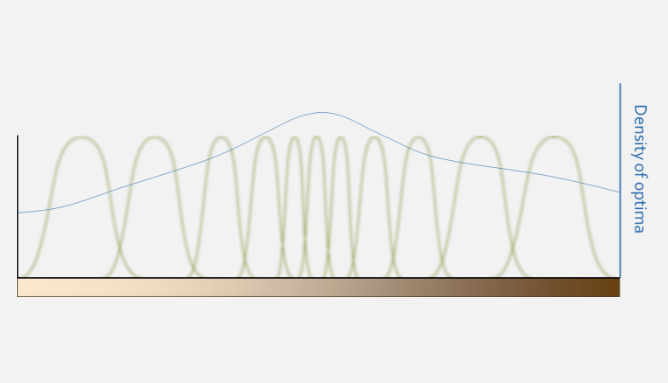
Optima ≥ 10 000 mg kg-1
Highly toxic conditions (Cu)
Large niche widths



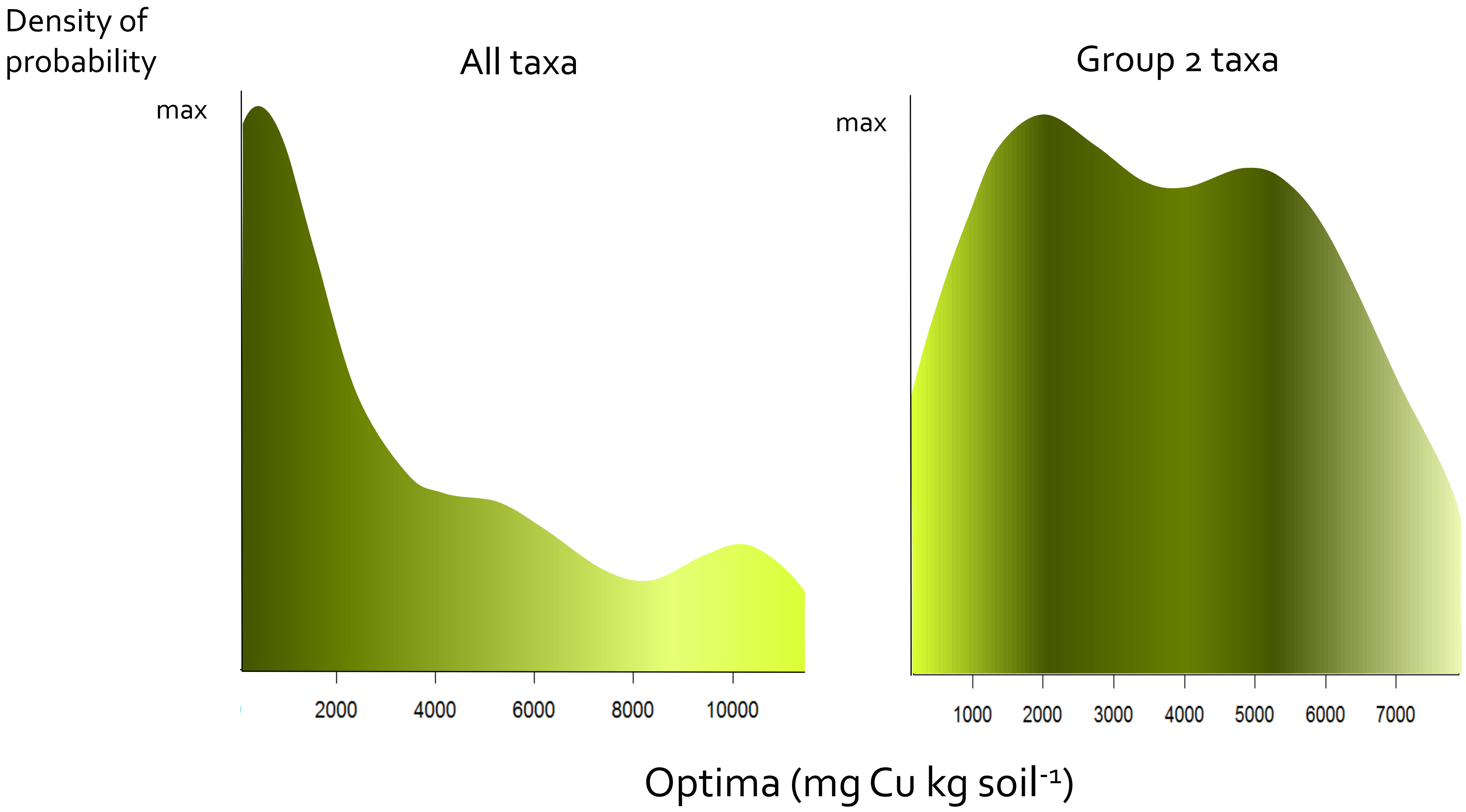
● = niche optima
▬ = niche width

Hypothesis 1
Optima are packed on mesic position

Along resource gradient



Along copper gradient



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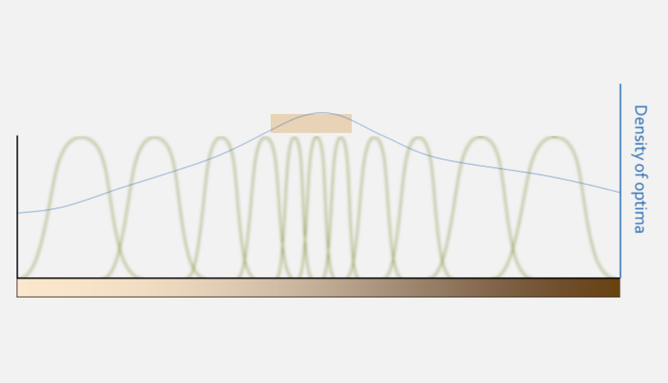
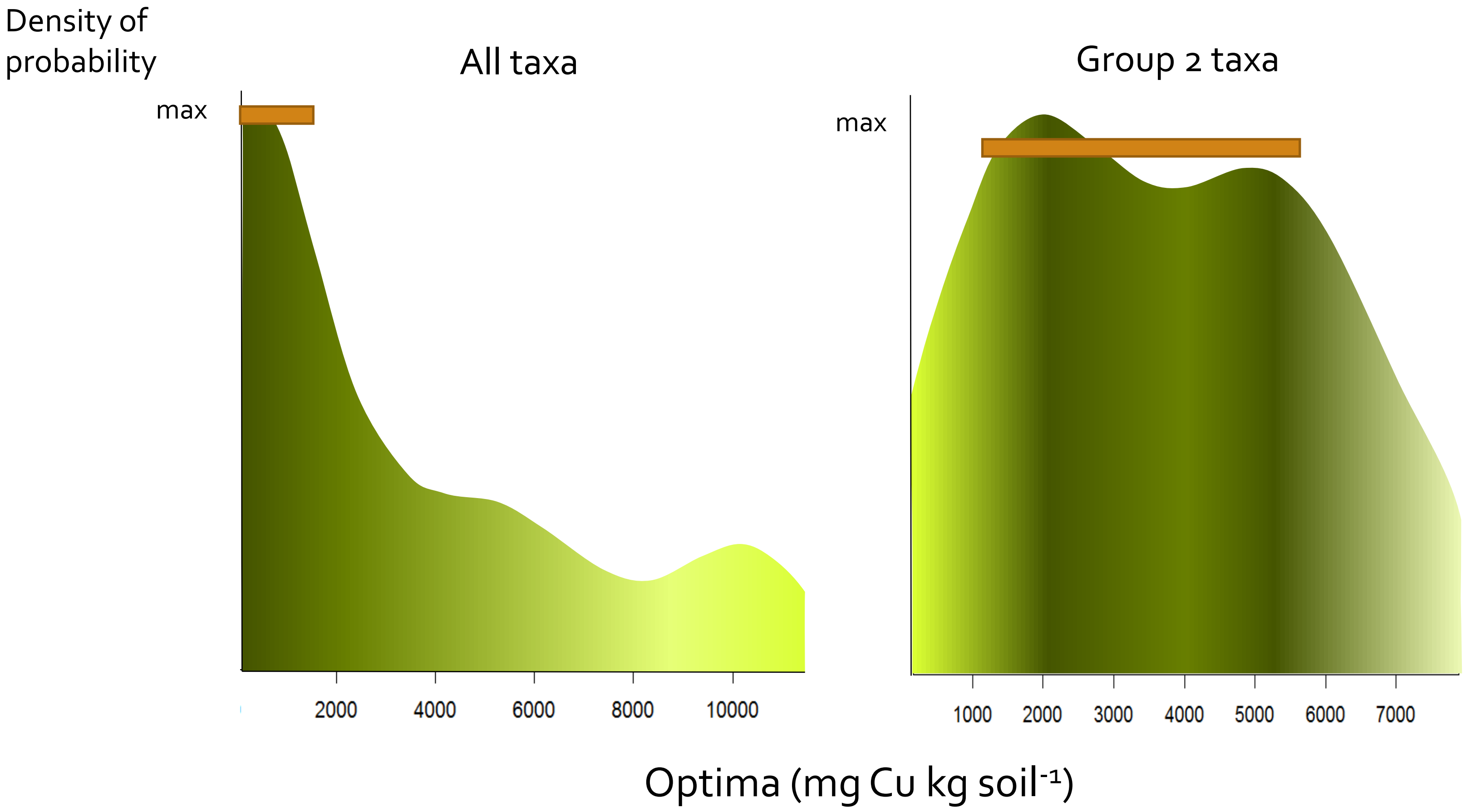
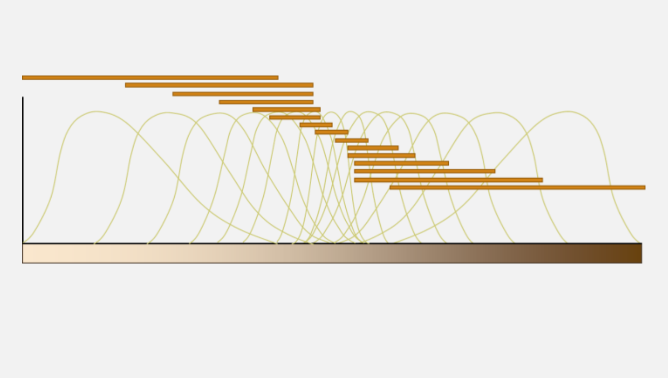


Along copper gradient

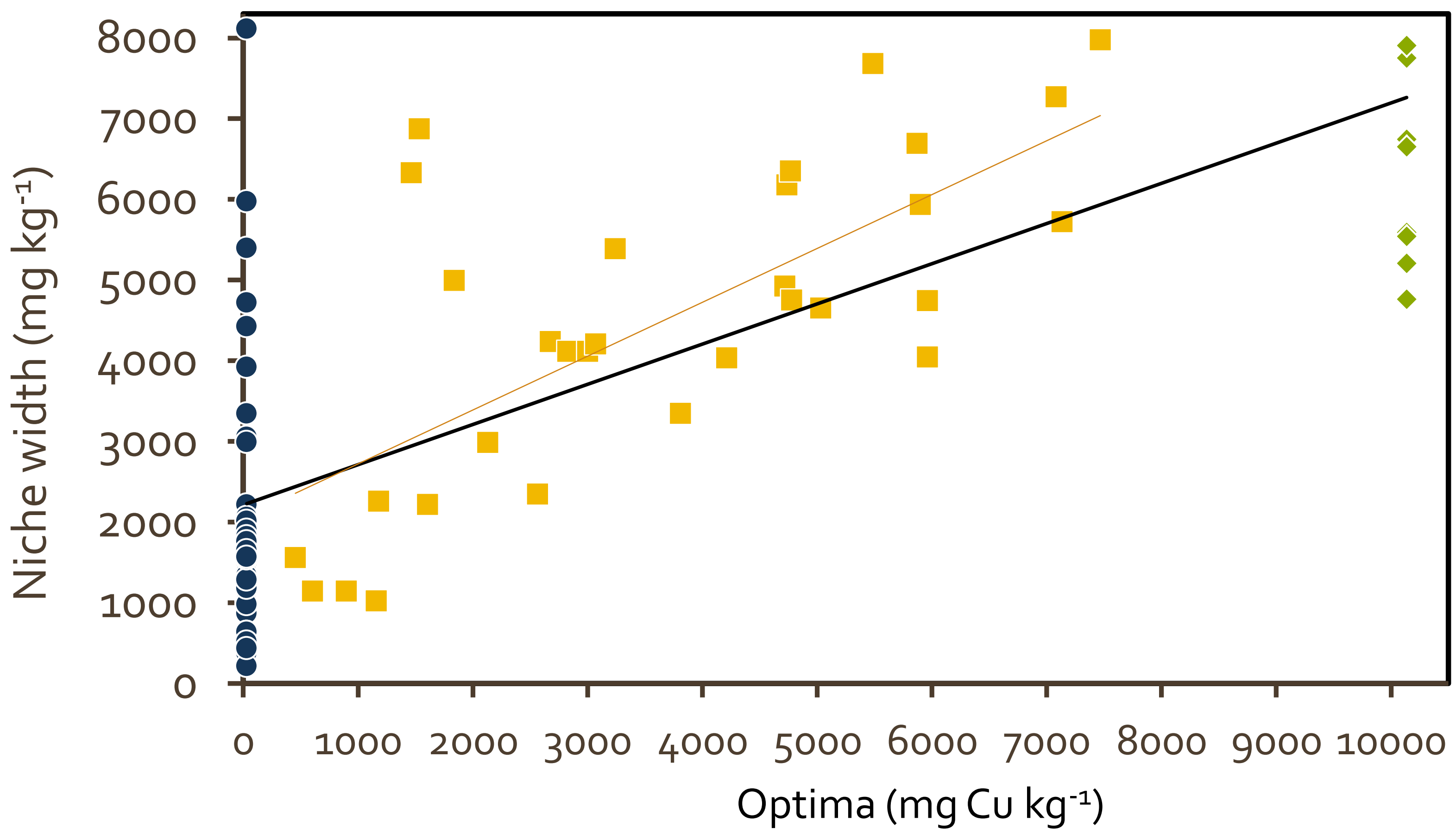


Hypothesis 2
Niche width are narrower on mesic positions

Along resource gradient



Along copper gradient



All taxa:

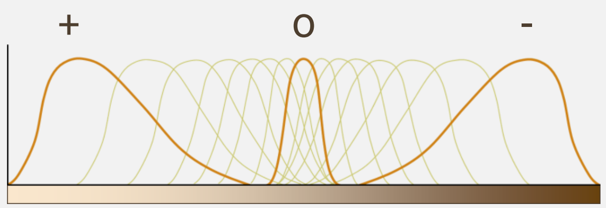
$R^2 = 0.54$
p-value < 0.001

Group 2 only

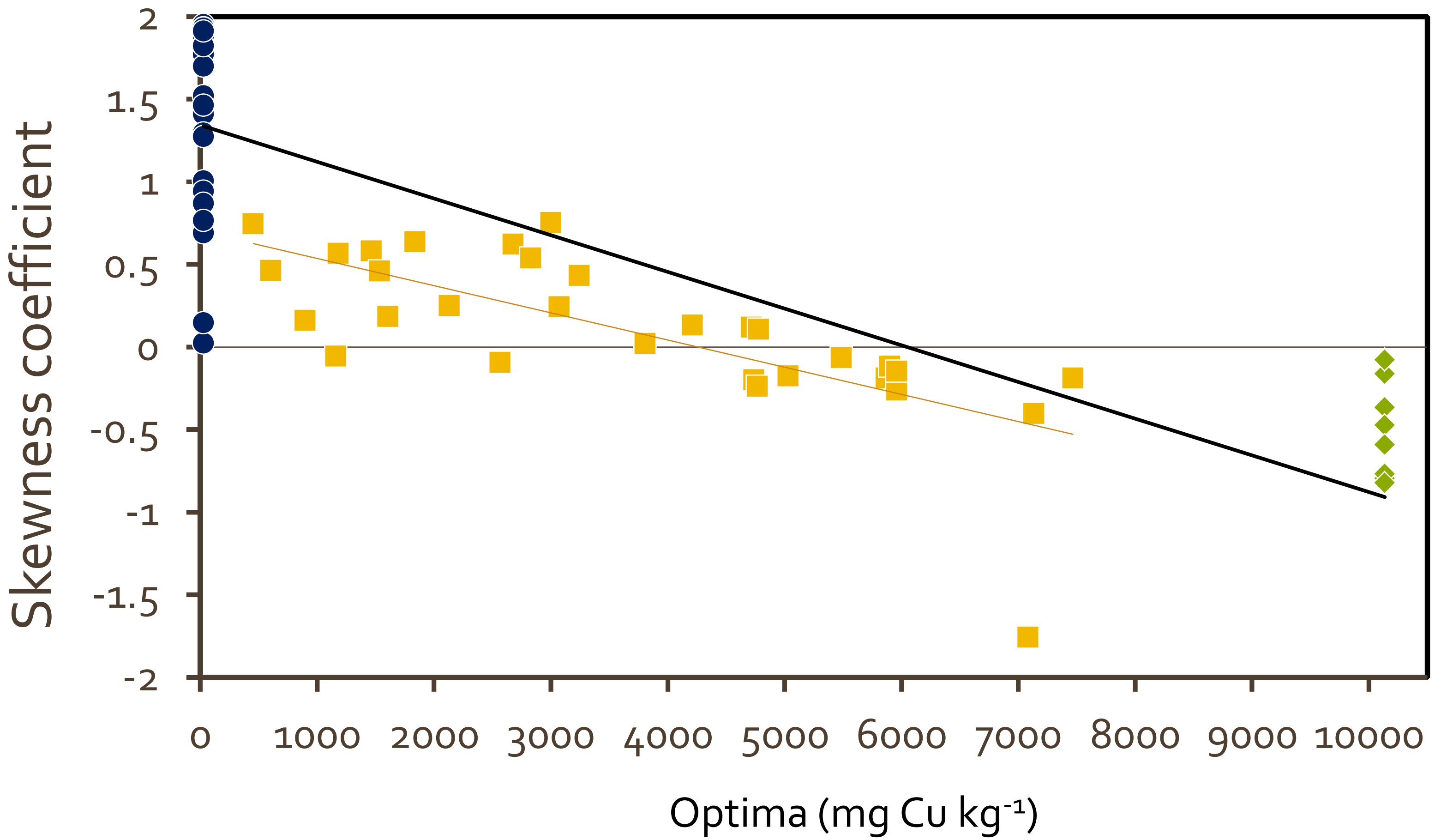
$R^2 = 0.50$
p-value < 0.001

Hypothesis 3
Skewness is higher at the extremities of gradient

Along resource gradient



Along copper gradient



Group 2 only :

$R^2 = 0.52$

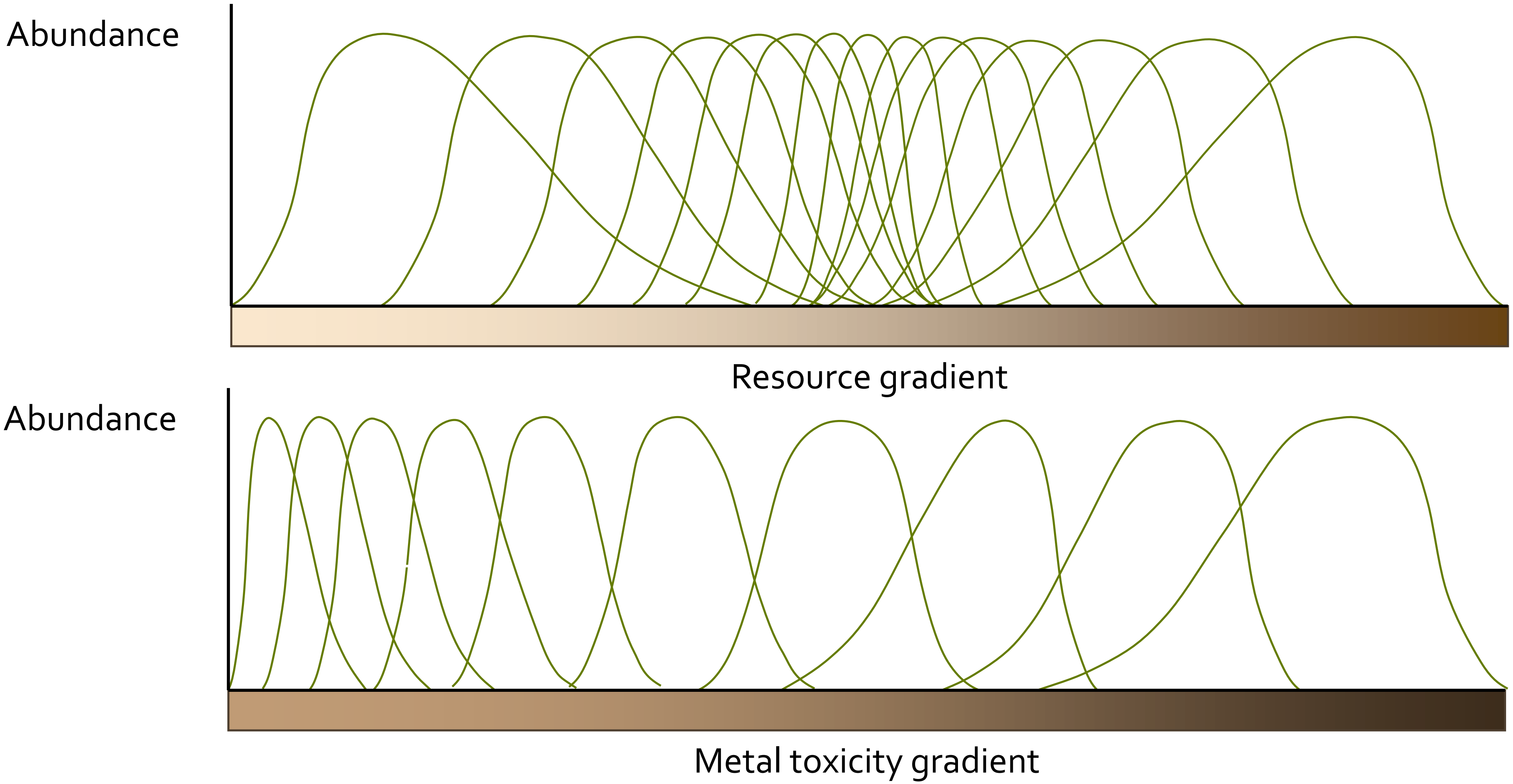
p-value < 0.001

All taxa :

$R^2 = 0.66$

p-value < 0.001

Comparison
of theoritical niche distributions



Implication for conservation

Botanical garden

Phytostabilization strategies

56th IAVS Symposium
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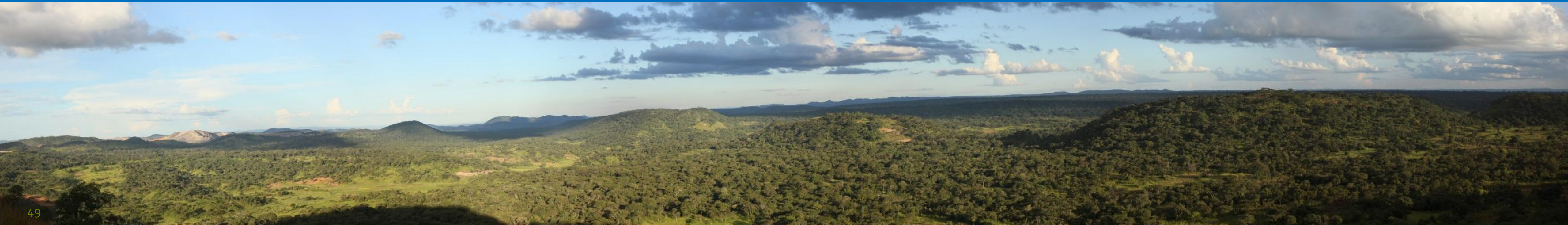
Thank you for your attention

sylvain.boisson@ulg.ac.be

More informations : **copperflora.org**

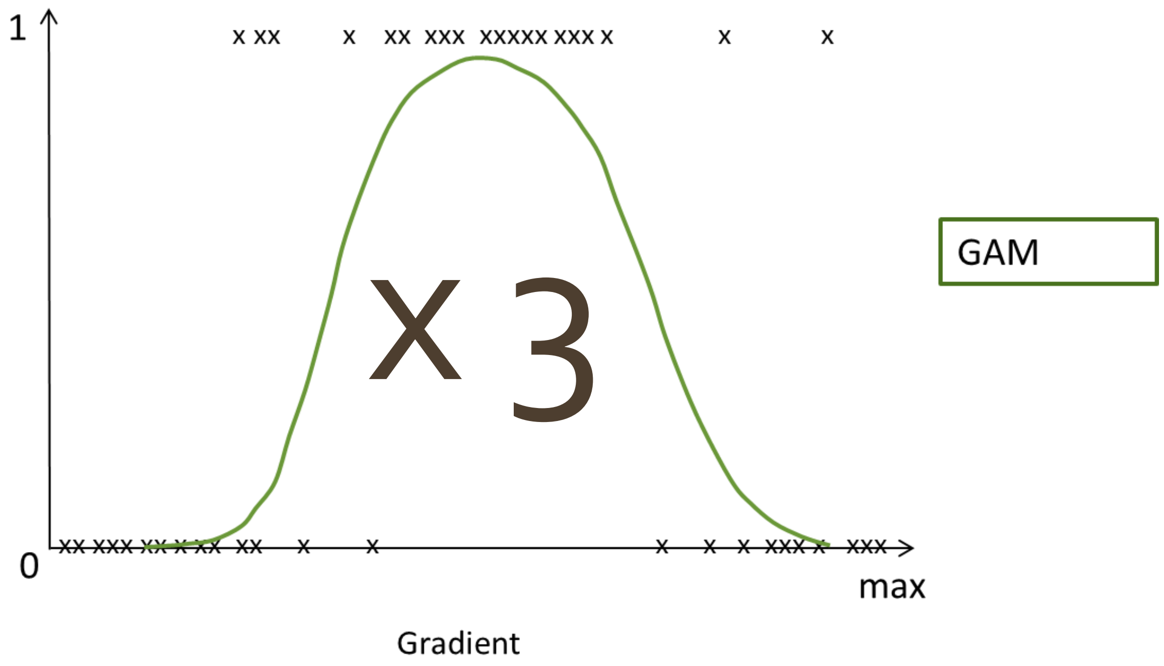


Copperflora

- Mining

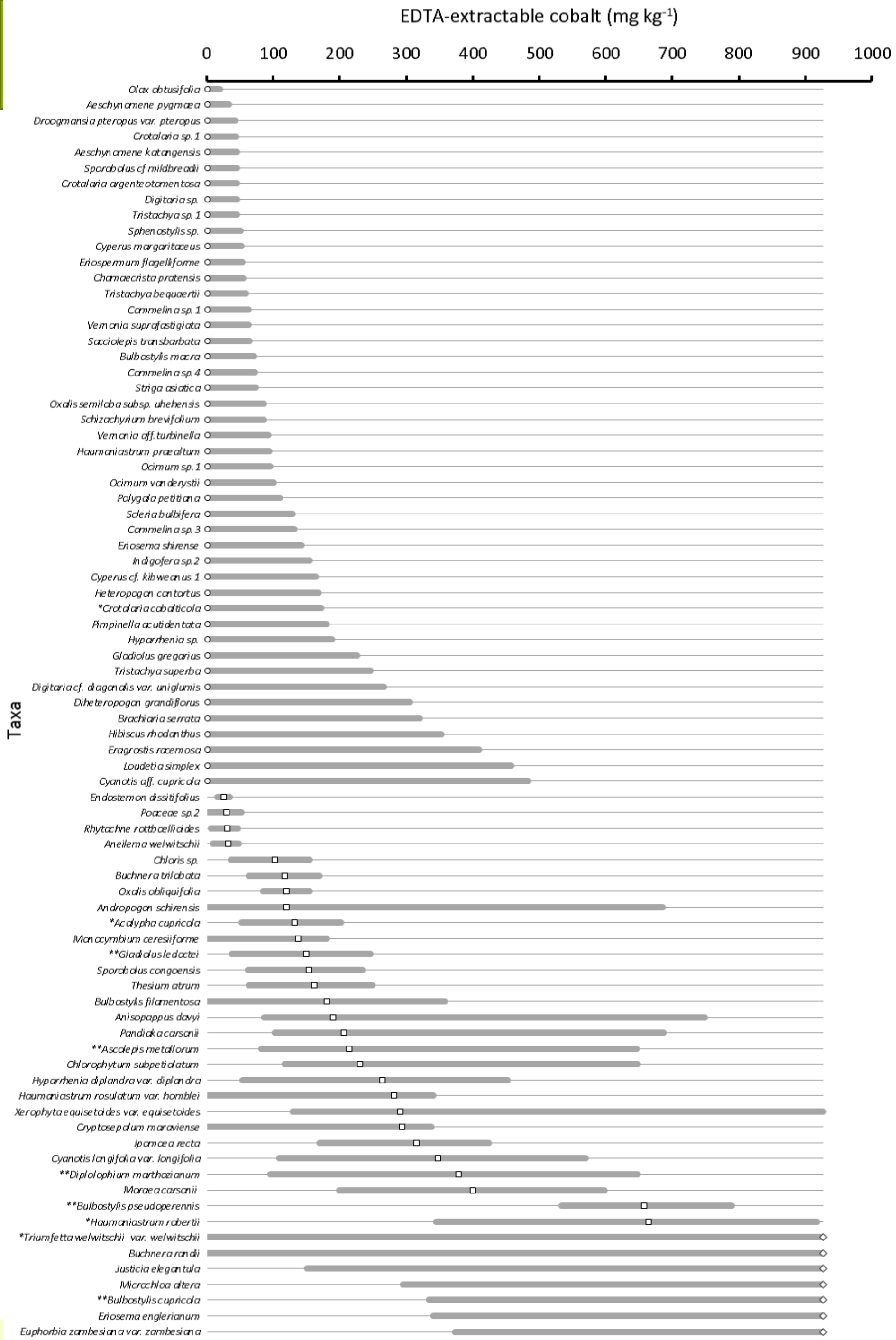
Modeling & analysis

- Select taxa with occurrence ≥ 8 in dataset (=80 taxa)
- Generalized additive model (Cu and Co) (Hastie & Tibshirani, 1990)
  - Non parametric method, robust
  - Logistic approach (0/1)
- 3 degrees of smoothing by taxon
  - Selection with Akkaike Information Criterion



Taxa distribution

Along cobalt gradient



- Range : 2 – 900 mg kg^{-1}

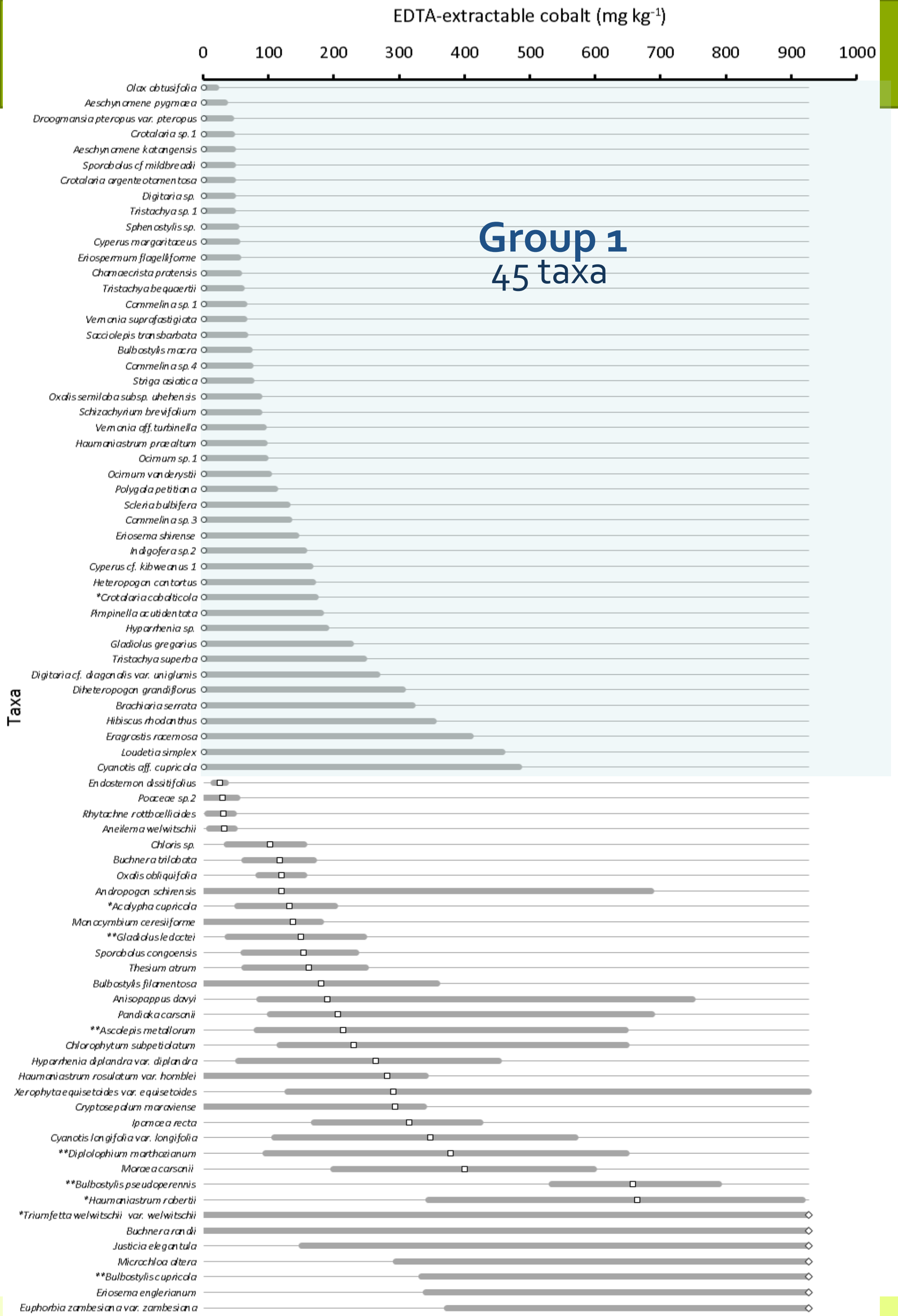
= niche optima
= niche width

Taxa distribution

Along cobalt gradient

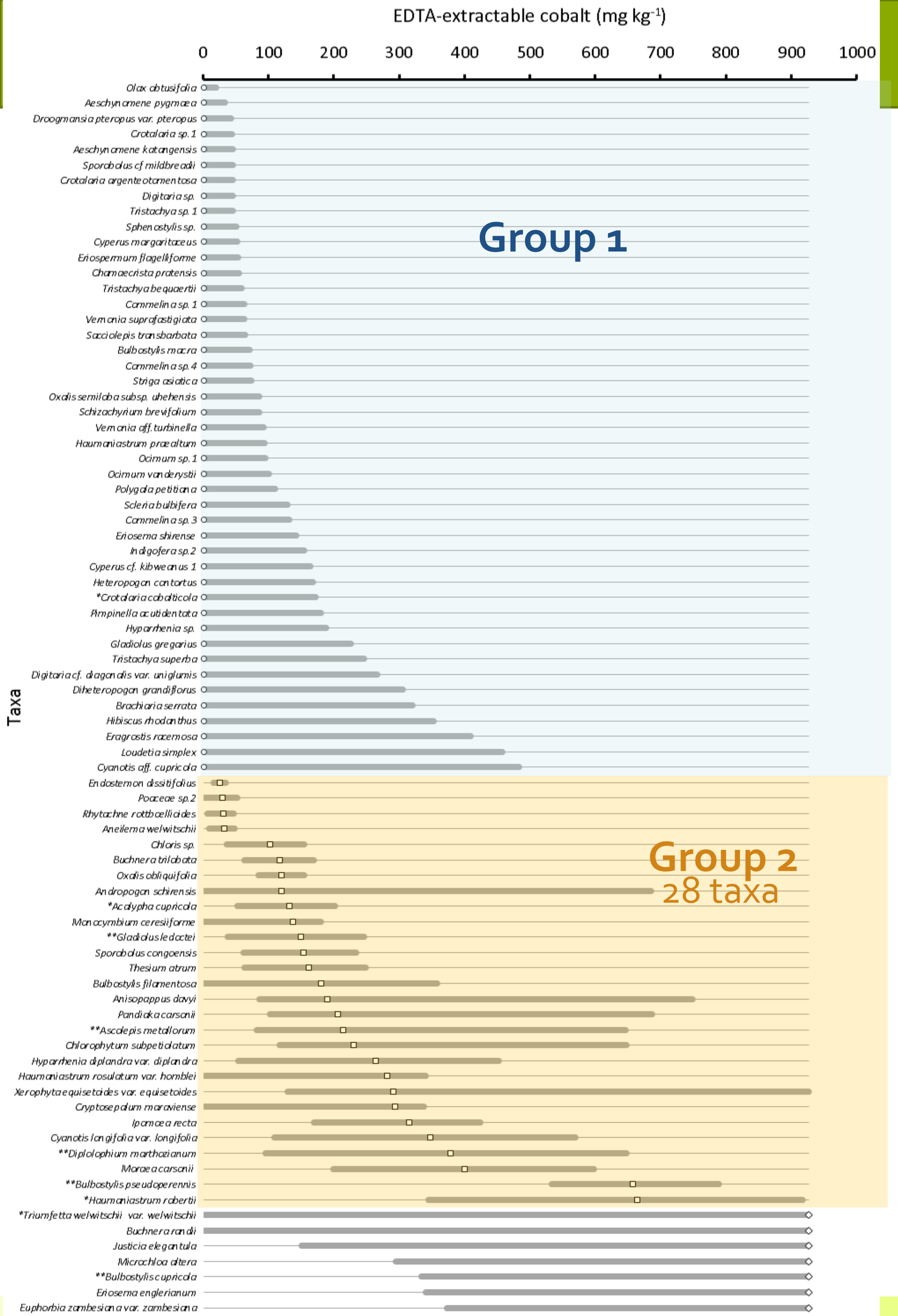
Optima ≤ 2 mg kg^{-1}

- Range : 2 – 900 mg kg^{-1}
- Group 1 : 45 taxa



= niche optima

= niche width

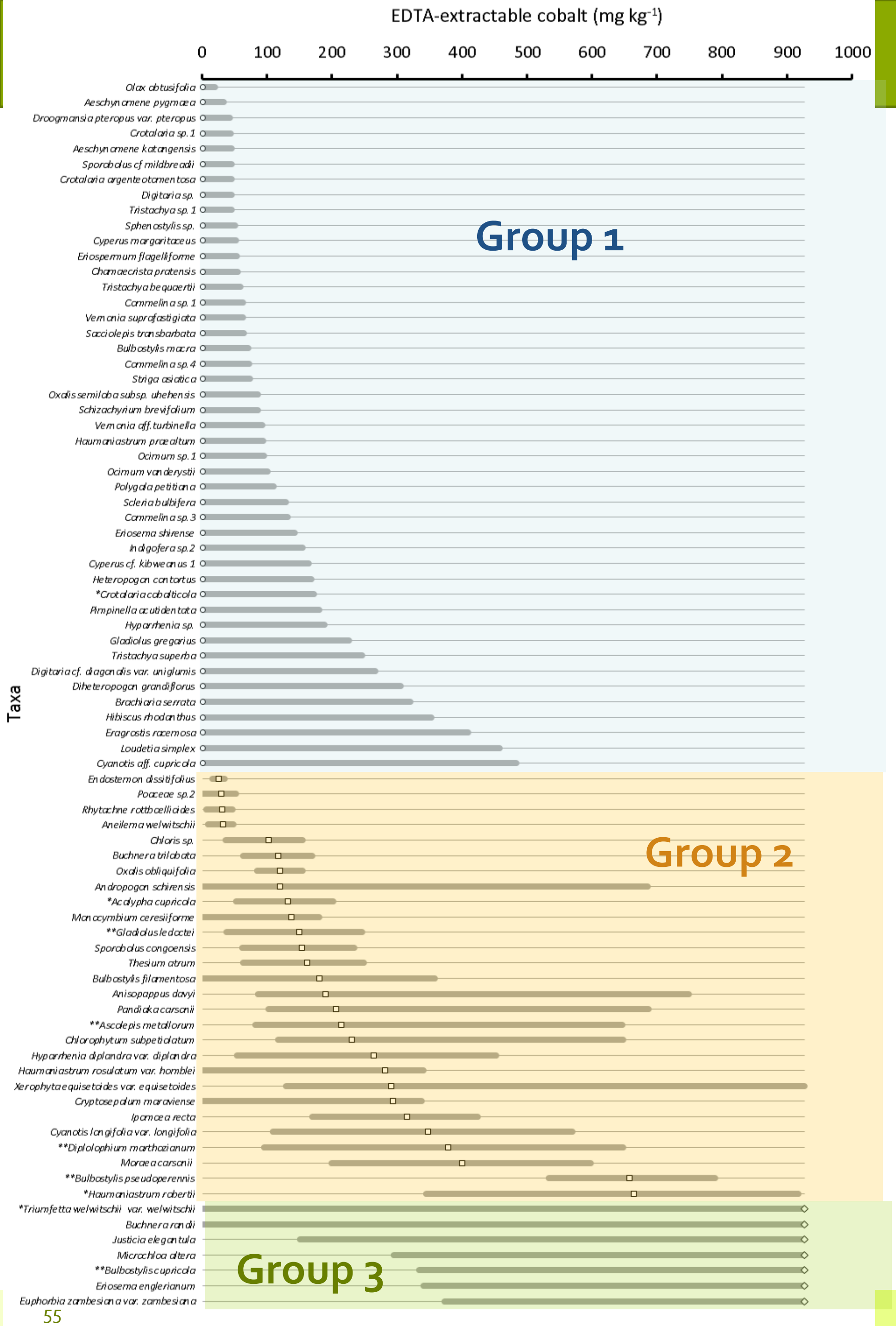


Taxa distribution

Along cobalt gradient

- Range : 2 – 900 mg kg^{-1}
- Group 1 : 45 taxa
- Group 2 : 28 taxa

= niche optima
= niche width



Taxa distribution

Along cobalt gradient

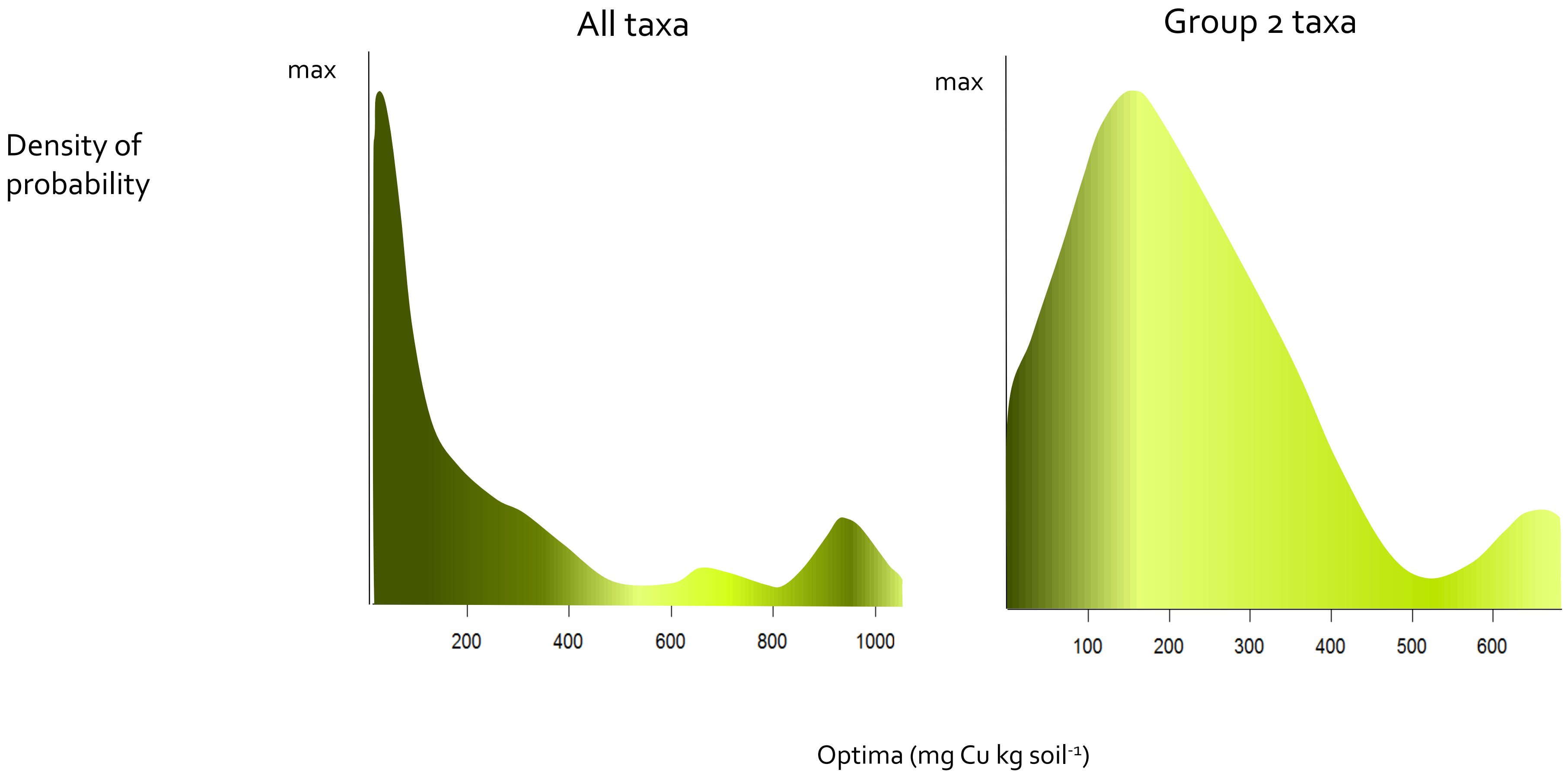
- Range : 2 – 900 mg kg^{-1}
- Group 1 : 45 taxa
- Group 2 : 28 taxa
- Group 3 : 7 taxa

= niche optima

= niche width

Density of optima

Along cobalt gradient



Niche width depends on niche optimum

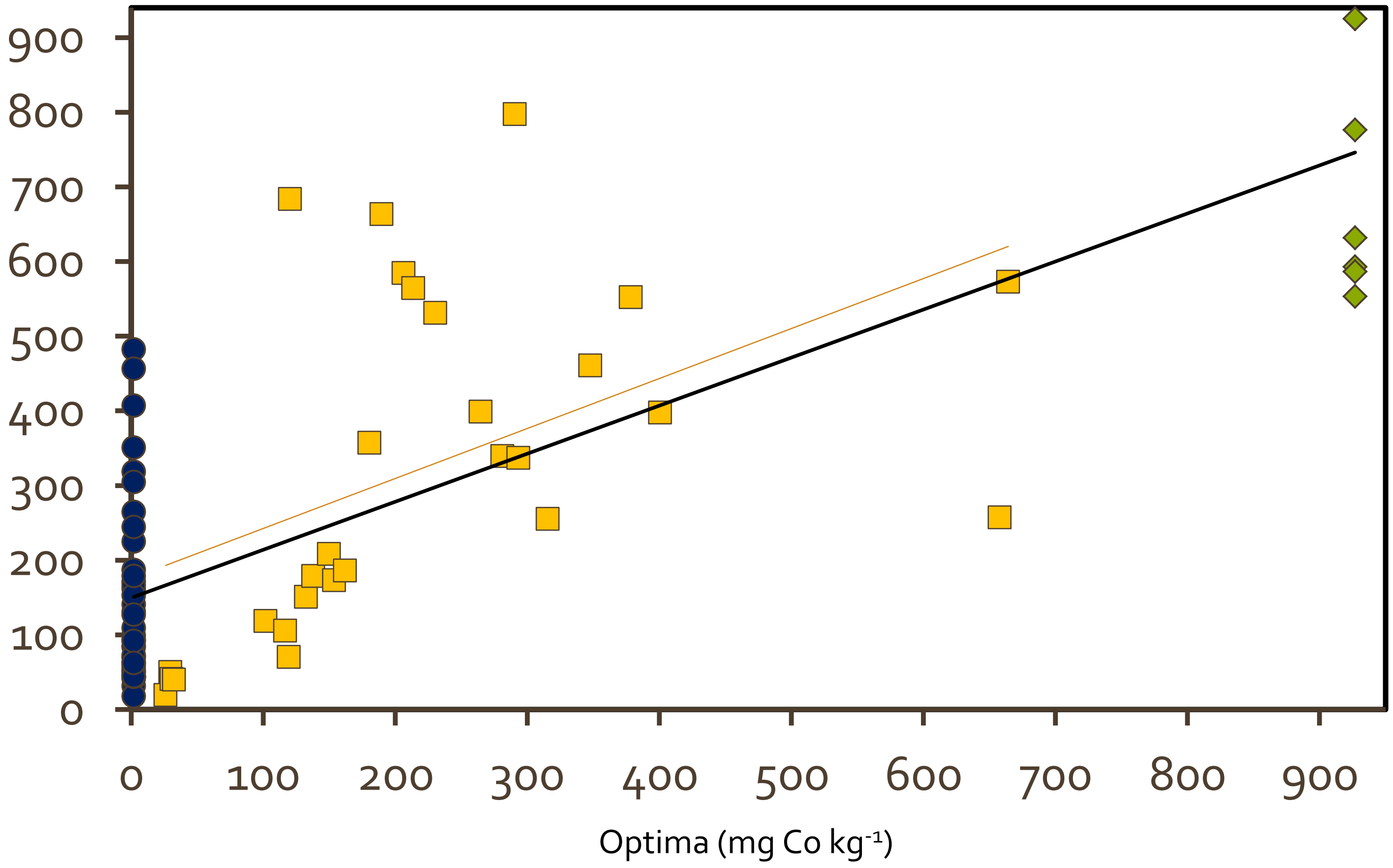
Along cobalt gradient

All taxa :

$R^2 = 0.57$
p-value < 0.01

Group 2 only :

$R^2 = 0.23$
p-value < 0.01

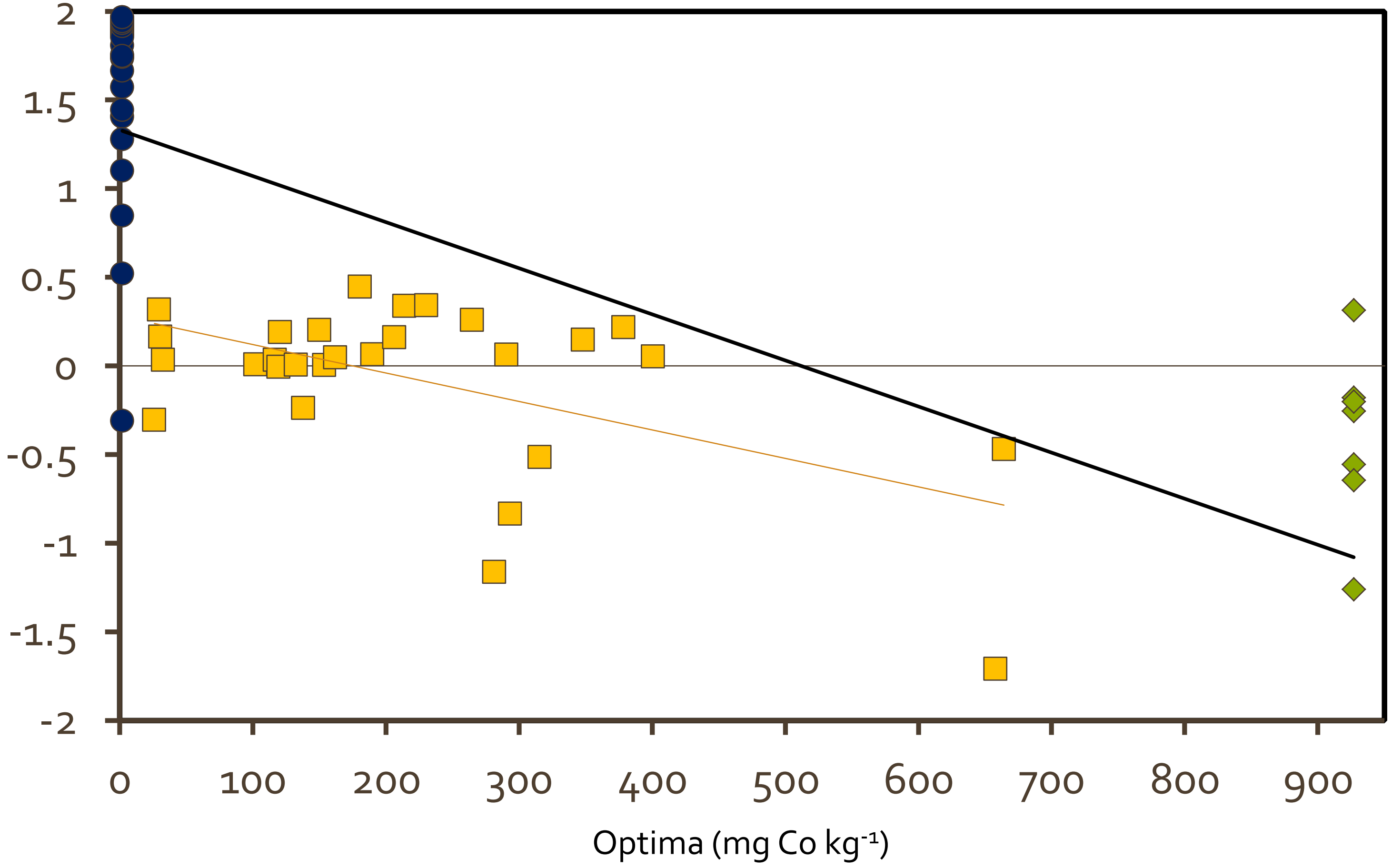


Skewness depends on niche optimum

Along cobalt gradient

All taxa :
$R^2 = 0.48$
p-value < 0.001

Group 2 only :
$R^2 = 0.29$
p-value < 0.001



Niches distribution

Along copper gradient

- Gradient : 0 – 10 000 mg kg^{-1}
- 11 % highly tolerant taxa
- For group 2, optima are uniformly distributed along gradient

Along cobalt gradient

- Gradient : 0 – 1000 mg kg^{-1}
- 9 % highly tolerant taxa
- For group 2, optima are packed on lowest concentrations

<u>Niche width and niche skewness depend on optimum location on the gradient</u>

Assumptions assumed for resource gradient are verified on metal gradient

! Mesic conditions are found at low metal concentrations

! Copper is an essential element <> Cobalt is a beneficial element

Annexes

Endemics

Cu (mg kg-1)

	Médiane	1er Quartile	3ème Quartile	3Q-1Q
B. lobelioides	113	86	243	157
T. coerulea	126	77	172	95
L. deltombei	294	234	560	325
T. likasiensis	211	193	364	170
B. kisimbae	223	200	223	23
H. rosulatum	209	79	464	385
E. cupricola	1286	332	1313	981
S. neptunii	5325	1808	7170	5361
C. zigzag	7571	5320	8603	3283

Co (mg kg-1)

	Médiane	1er Quartile	3ème Quartile	3Q-1Q
B. lobelioides	53	43	65	22
T. coerulea	15	10	48	38
L. deltombei	15	9	28	19
T. likasiensis	15	10	44	33
B. kisimbae	51	37	51	13
H. rosulatum	2	10	49	38
E. cupricola	52	45	90	45
S. neptunii	33	30	207	177
C. zigzag	151	123	191	67