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Technosols Construction, pedogenesis and modeling

*Sophie Leguédais, Geoffroy Séré, Apolline Auclerc,
Françoise Watteau, Christophe Schwartz, Jean Louis Morel
Laboratoire Sols et Environnement, Nancy, France*

General outline of the talk

- Introduction
 - Technosol
 - Sediments
- 1- Sediments as parent materials of Technosols
- 2- Technosols as a remediation technique for sediments
- 3- Modelling Technosol pedogenesis to predict its evolution

What are Technosols?

- “Soils dominated or strongly influenced by human-made material”
 - Internat. Union of Soil Science (2006, 2014)



Pictures Florentin, Huot, Morel, Nehls, Schwartz, Séré

- Stratigraphic markers of the Anthropocene?
Anthropogenic soils are the golden spikes for the Anthropocene

Giacomo Certini¹ and Riccardo Scalenghe^{2,3}

The Holocene
21(8) 1269–1274
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DOI: 10.1177/0959683611408454
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Definitions of sediments

- In the field of environmental management
 - “Soil, sand, organic matter and/-or other minerals that tend to accumulate on the bottom of a water body” (US-EPA)
- In Earth sciences
 - “Naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, ice, or by the force of gravity” (Wikipedia)
 - Include terrestrial sediments
- Proposal of a definition adapted to the Anthropocene:
 - Include human activities as processes of weathering, erosion, and transport
 - Acknowledgement of the major driving force affecting the environment in the Anthropocene era
 - → “Naturally and **human-induced** occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, ice, gravity, **and humans**”

Rationale for an Anthropocene definition of sediment

- Urban sprawl
 - Cities are constructed on anthropogenic sediments which are covering natural soils...



The volume of soil and backfill materials extracted for the construction of the super-metro, Grand Paris Express represents, around 5,000 to 7,000 Olympic swimming pools.

Le Grand Paris face à une montagne de déblais

LE MONDE | 22.03.2013 à 11h22 • Mis à jour le 25.

Par Gilles van Kote

Abonnez-vous à partir de 1 €



Classer



Le Monde

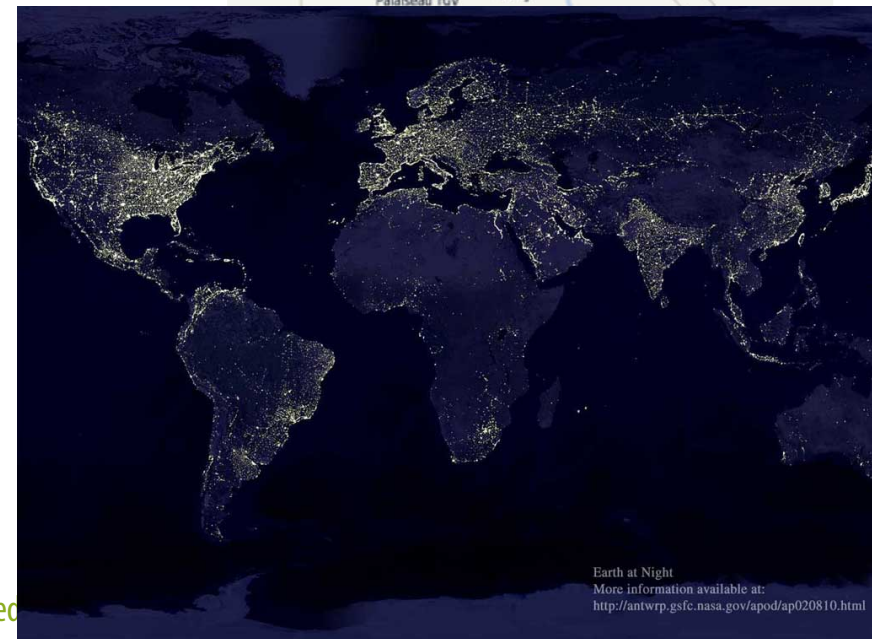
Recommander Partager

115 personnes le recommandent.

Inscription pour voir ce que vos amis recommandent.



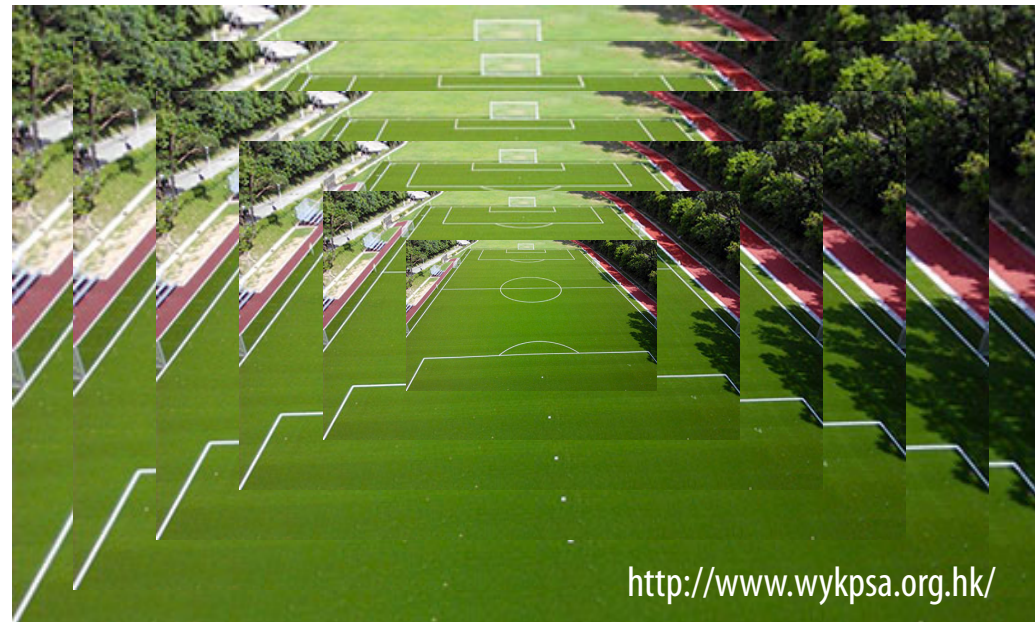
- and they represent up to 3 % of the world land surface
 - Liu et al., 2014; Schneider et al., 2009; Seto et al., 2011



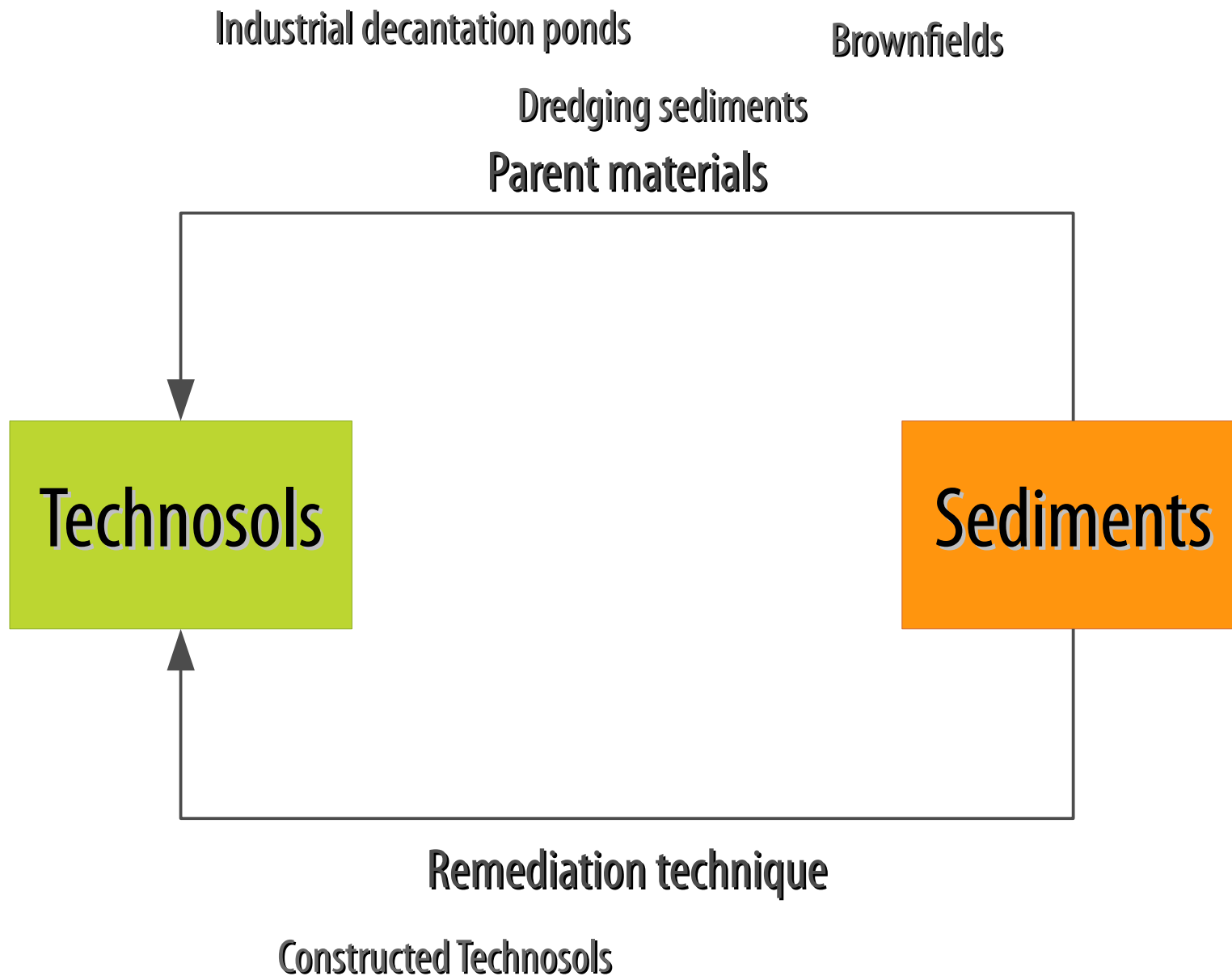
Earth at Night
More information available at:
<http://antwrp.gsfc.nasa.gov/apod/ap020810.html>

Rationale for an Anthropocene definition of sediment

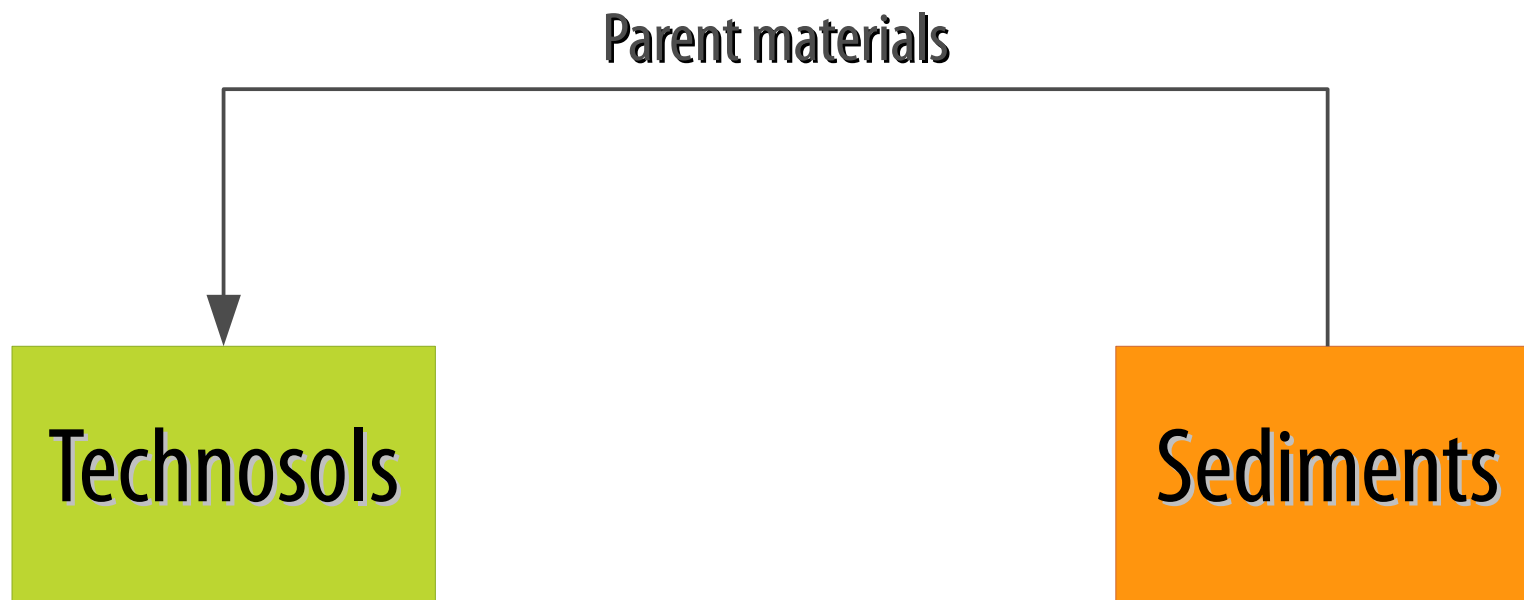
- Mining: n important source of anthropogenic sediments
 - = 21 Gt.y⁻¹ of soil materials extracted by mining activities
 - Hayes *et al*, 2015
 - around 30 soccer pitches per min



Technosols and sediments: a dual relationship



1- Sediments as parent materials of Technosols



Outline of part 1

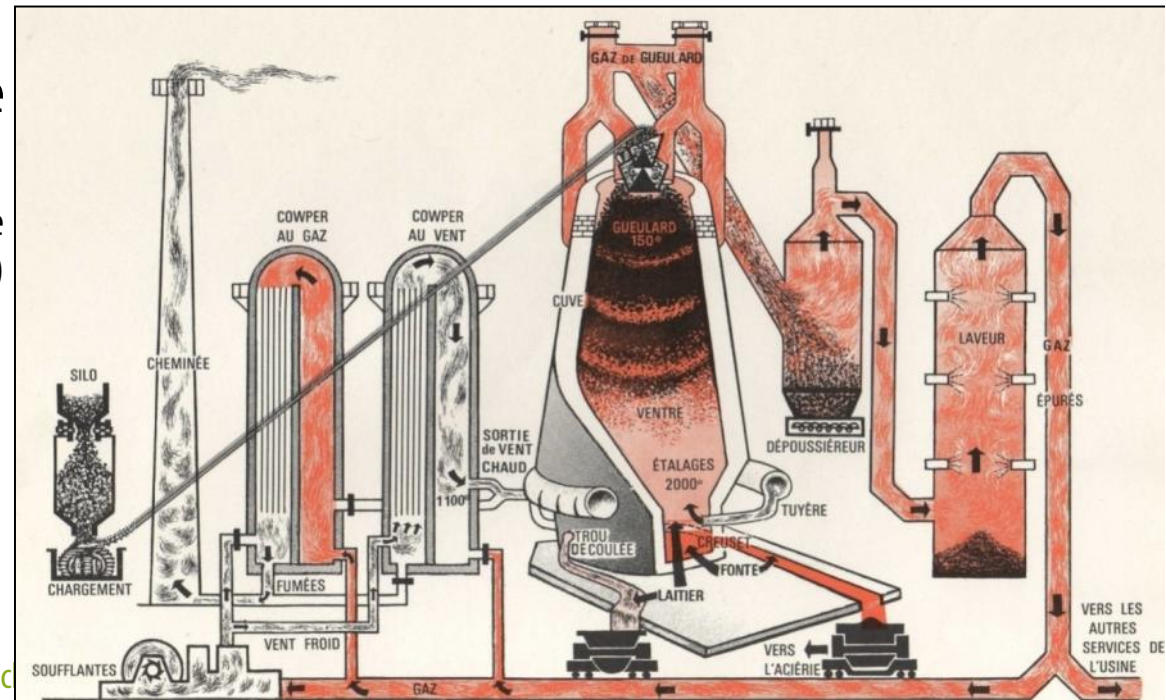
- One example of Technosol developed of anthropogenic sediment
 - Risk assessment
 - Pedogenesis

Example of the decantation ponds of the steel industry

- Blast furnace sludge, by-products of iron and steel industry
 - not recycled because of the high contents in Pb and Zn
 - often dumped into settling ponds

Blast furnace and annexes

(source : Chambre syndicale de la sidérurgie française)



Studied site

Aerial view of the settling pond of Ban-la-Dame
(Pompey-Frouard-Custines- Lorraine, North-East France)

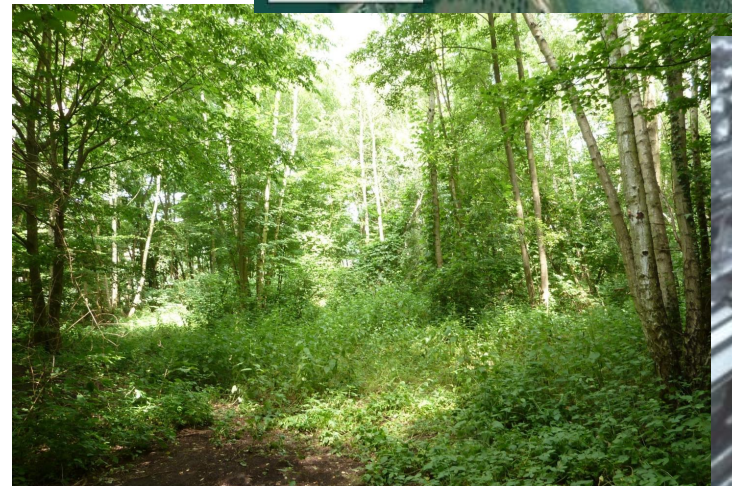


History of the industry

- 1872: setting up of steelworks
- 1922: beginning of the production of ferromanganese
- 1950: beginning of the production of special steel, probable cessation of sludge dumping in the settling pond
- 1986: closure of steelworks
- 1990s: site redevelopment

Characteristics of the settling pond

- 2.6 ha
- deposit depth: probably 8-10 m
- groundwater: 7-8 m depth
- vegetation: diversified deciduous forest

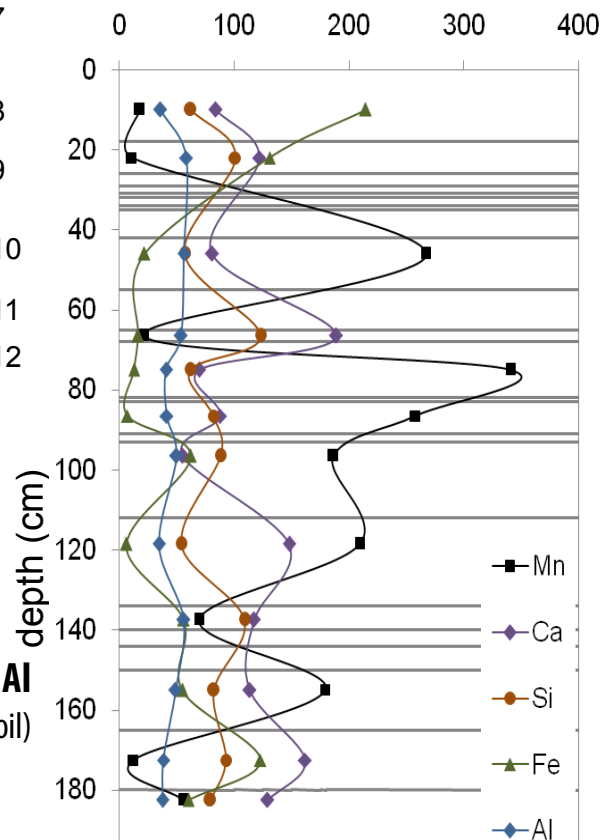
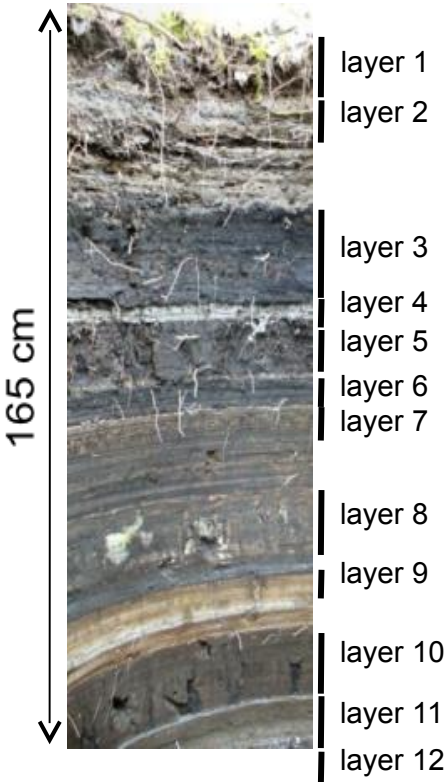


1950s, Gerber (2005)

Technosol characteristics

- Spolic Technosol
- Chemical composition

- High variability ↔ the layers
- Main elements: Mn, Ca, Si, Fe, and Al
- **Very high contents of metals and metalloids (Pb & Zn)**



Huot *et al.*, 2013 (JSS)

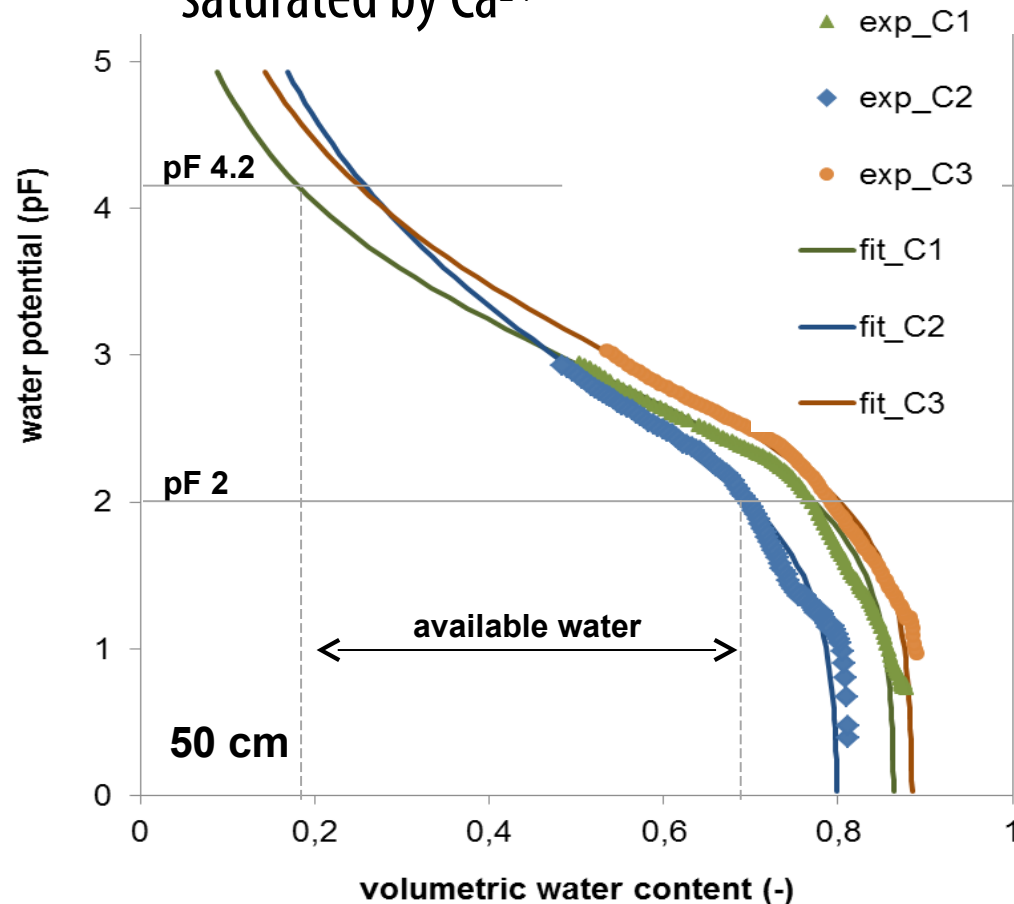
Mn, Ca, Si, Fe and Al
(g kg⁻¹ dry soil)

	settling pond of Pompey			geochemical background alluvial plain of Moselle river	
	mean *	min	max	mean **	max
	mg kg ⁻¹ of dry soil				
As	239	53	1 131	20	50
Cd	106	10	352	2	5
Cr	70	24	193	75	200
Co	13	2	34	15	50
Cu	205	78	657	30	100
Ni	108	8	272	40	100
Pb	24 808	2853	108 850	30	100
V	422	30	1 191	100	500
Zn	21 051	3 940	81 483	120	500

Technosol characteristics

- Chemical properties

- pH slightly **alkaline** (pH 7.5-8)
- high content of **carbonates** (6 to 32 %)
- **high CEC** (24 to 83 cmol⁺ kg⁻¹)
- saturated by Ca²⁺

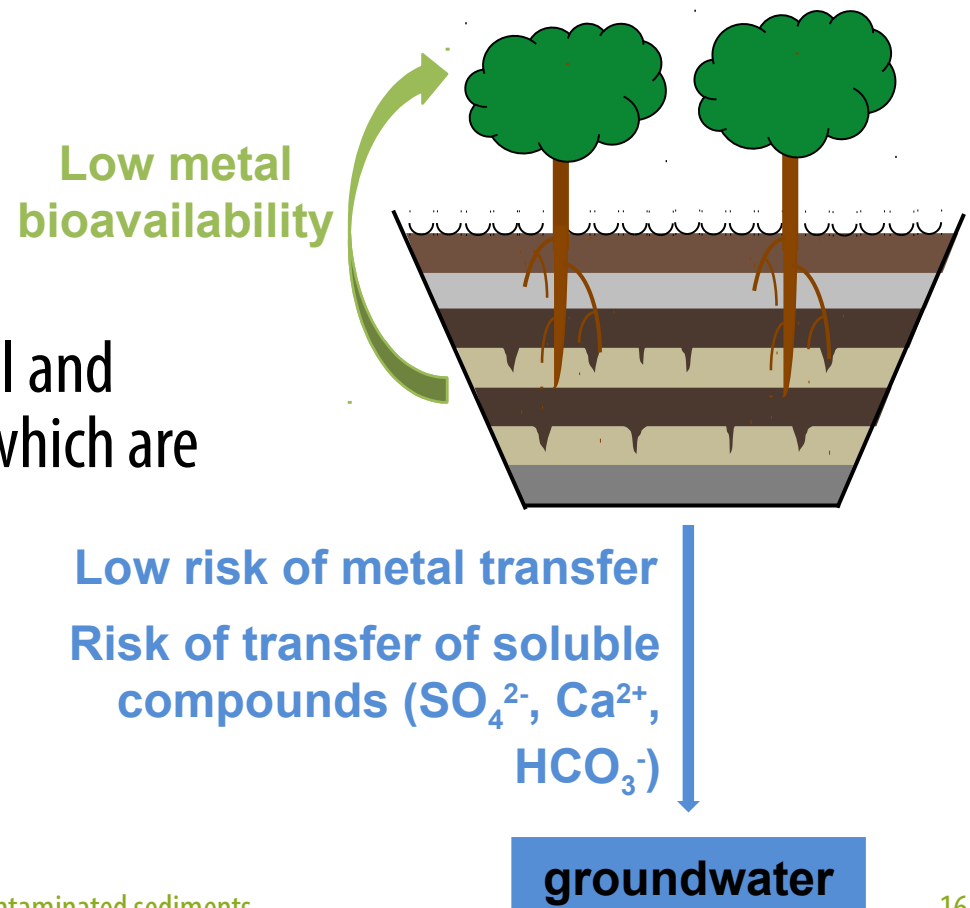


- Physical and hydraulic properties

- fine materials dominated by particles < 50 μm
- low bulk density (0.2 to 0.7 g cm⁻³)
- high total porosity (75 to 90 % (v/v)) dominated by micropores (d < 0.2 μm)
- high specific surface area (50 to 320 m² g⁻¹)
- **high water retention** capacity and thixotropy
- semi-permeable materials (2.10⁻⁶ to 1.10⁻³ m s⁻¹)

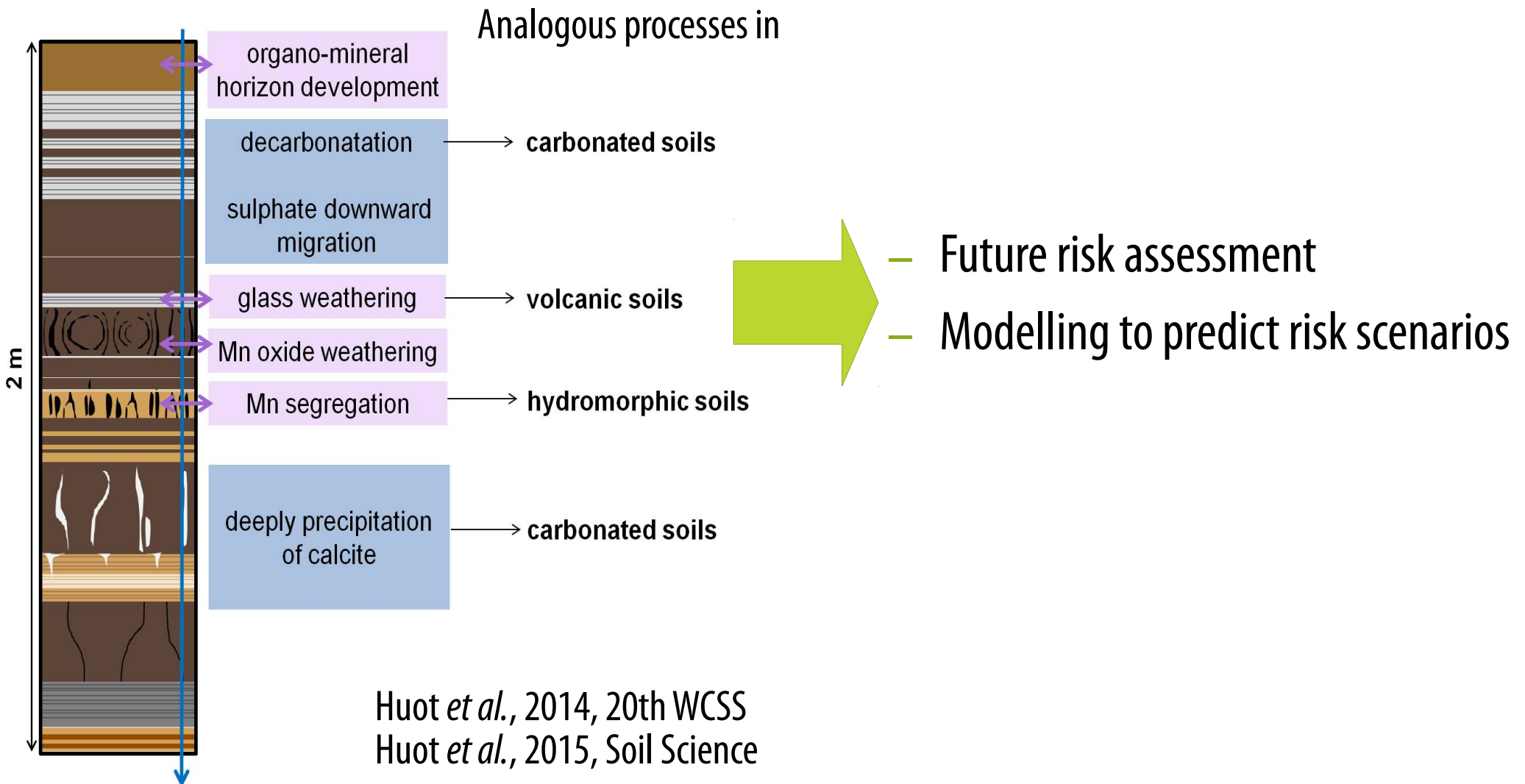
Risk management?

- Significant range of soluble compounds (sulfates, carbonates) may be released into water
- But metal fluxes are limited due to:
 - a low metal solubility
 - a high water retention
 - in relation to the constituents, chemical and physical properties of these materials which are favorable to metal retention.



Conclusion on part1: future evolution?

- Observed pedogenic processes



2- Technosols as a remediation technique for sediments

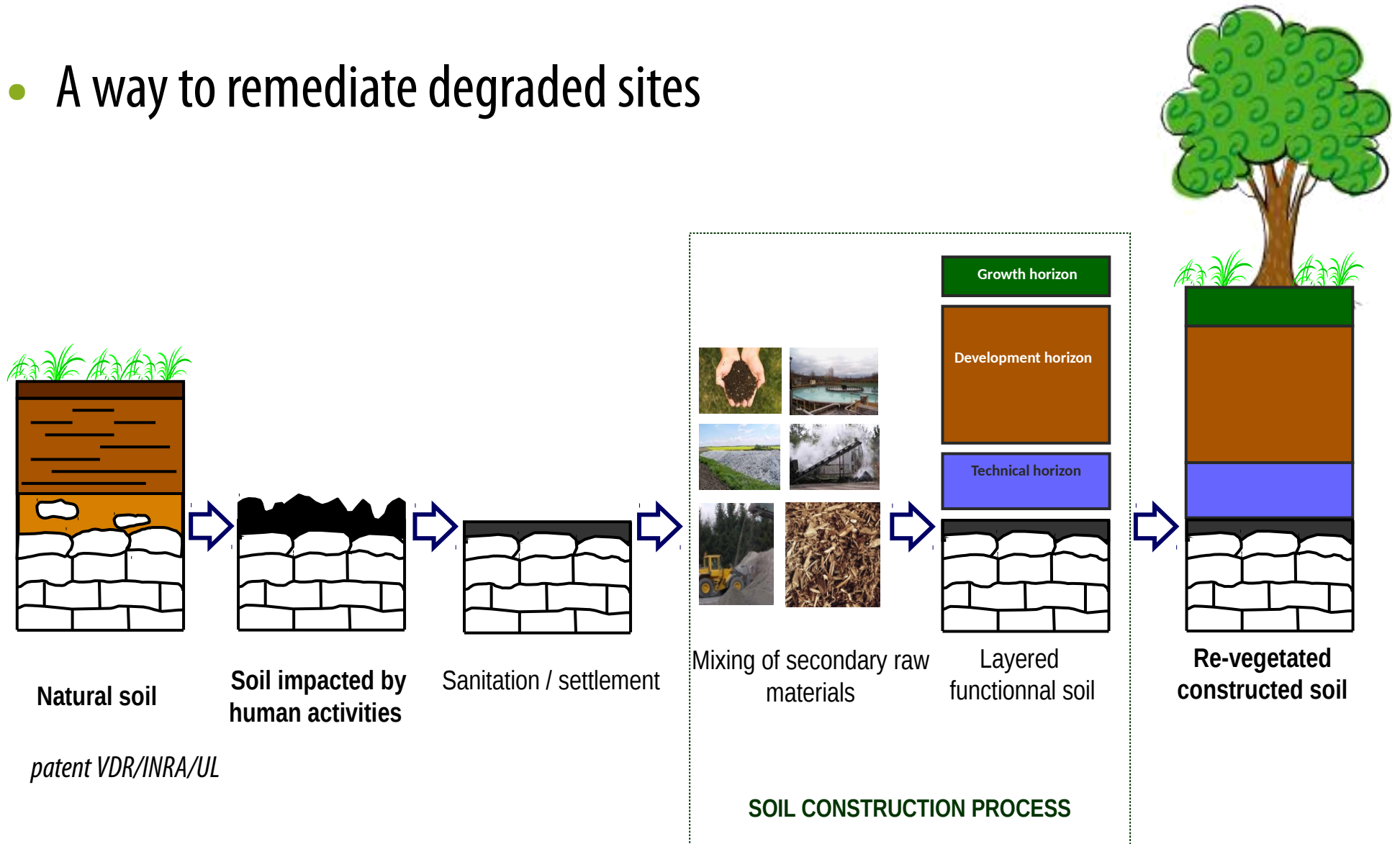


Outline of part 2

- General concepts of Technosol construction
- Feasibility of soil construction with wastes and by products
- Example 1

The Technosol construction approach

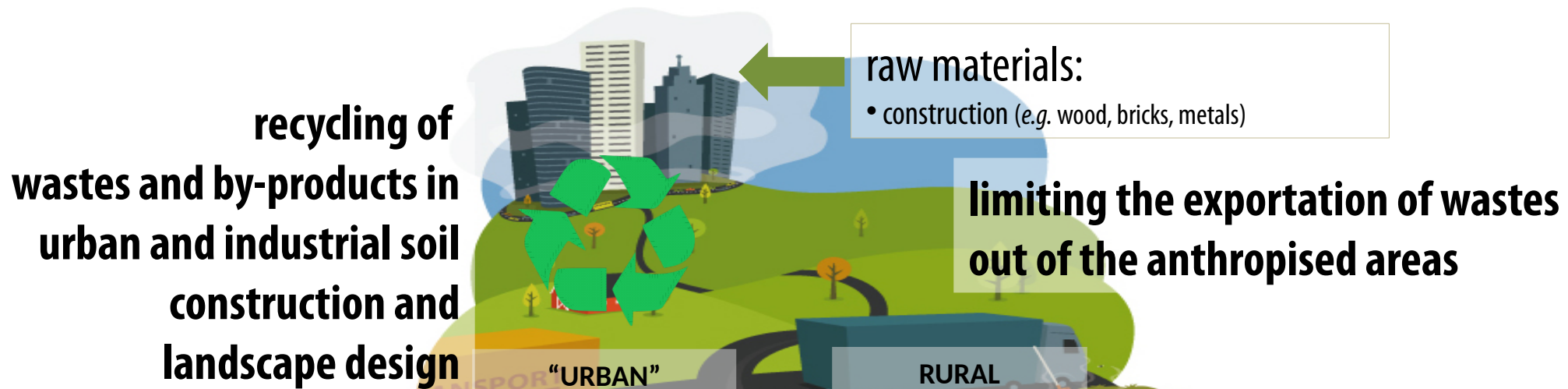
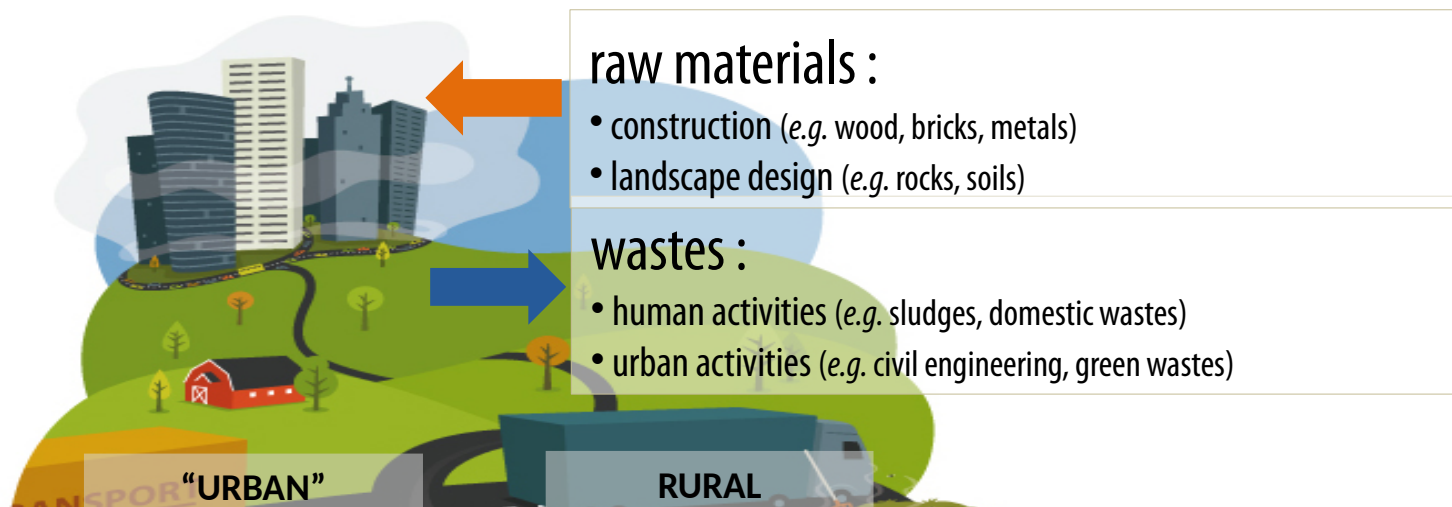
- A way to remediate degraded sites



Séré et al. (2008) *J Soils Sediments* 8:130-136
Séré et al. (2010) *J Soils Sediments* 10:1246-1254

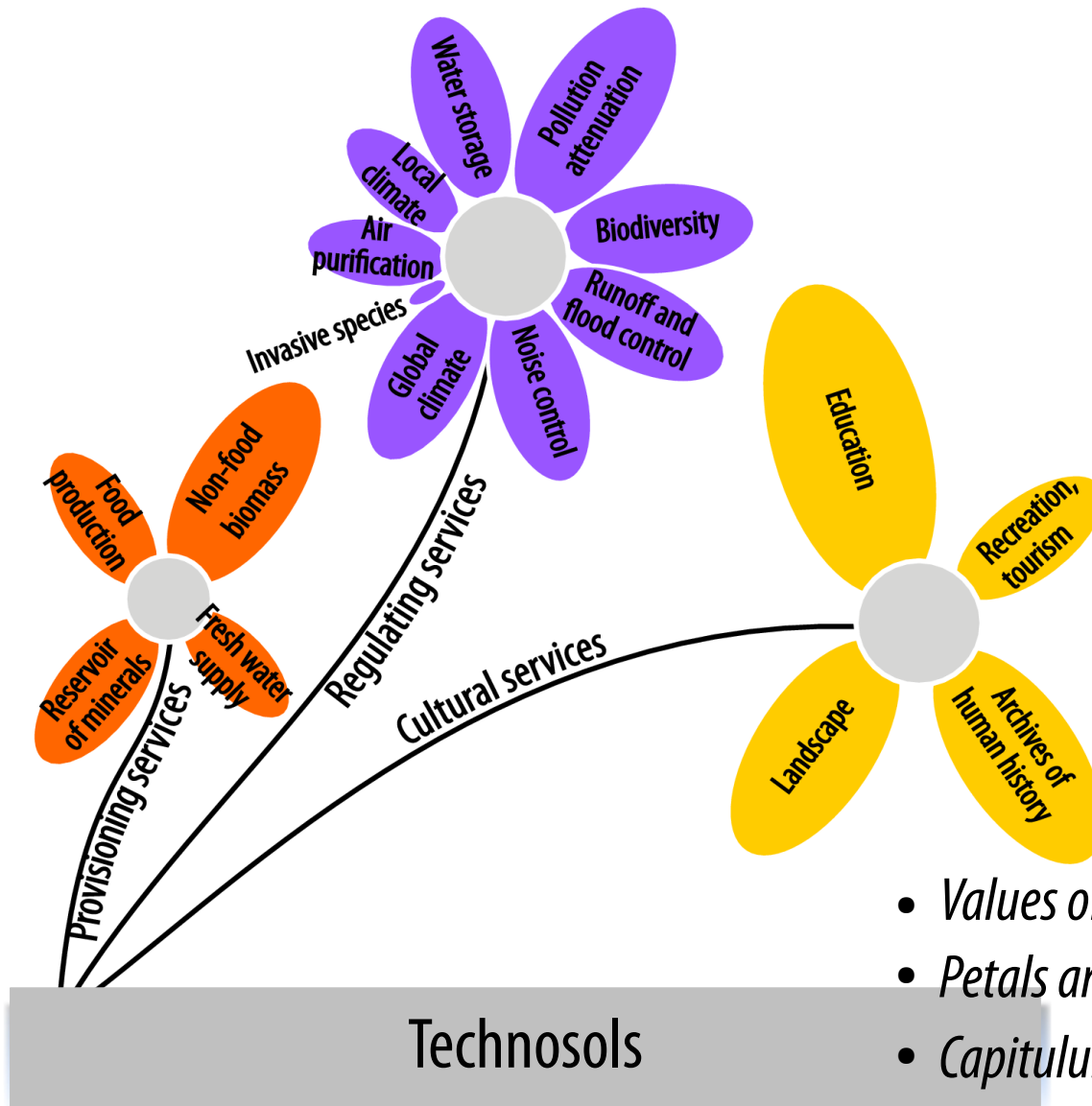
The Technosol construction approach

- A way to spare natural resources



The Technosol construction approach

- A way to enhance the provision of ecosystem services

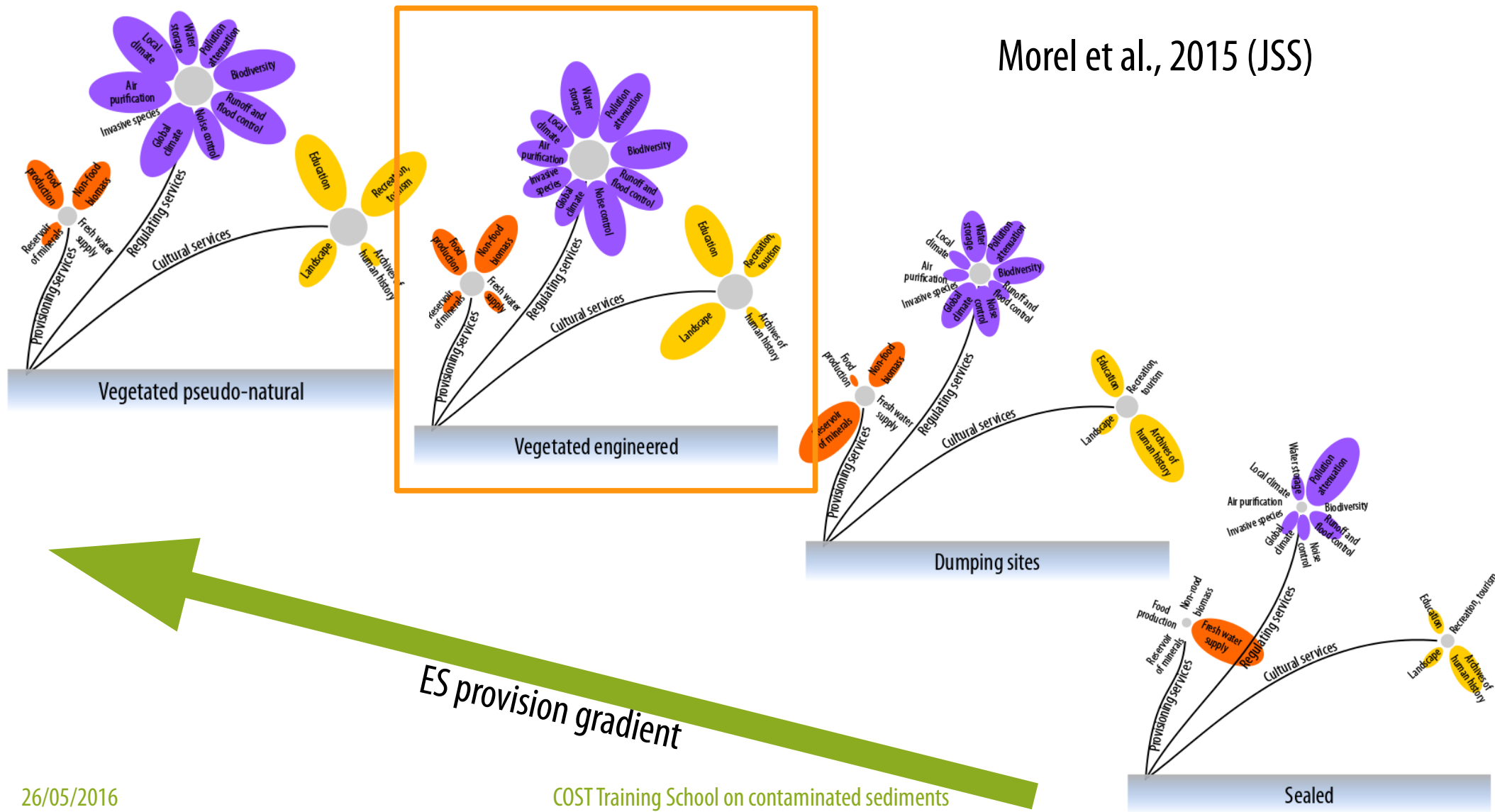


- Values of ES from Morel et al., 2015 (JSS)
- Petals area μ ES value
- Capitulum area μ averaged ES value for category

The Technosol construction approach

- A way to enhance the provision of ecosystem services

Morel et al., 2015 (JSS)

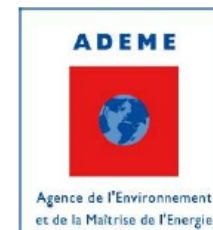


Feasibility of soil construction

- Is it feasible to create fertile substrates, which mimic natural soils, exclusively with wastes?
- Is the fertility of these mixtures predictable out of the characteristics of the constitutive materials?



AVEC LE SOUTIEN DE :



Selection of parent technogenic materials

EUROPEAN WASTE CATALOGUE (836)

eliminary filter

e.g., volume of production,
availability, low toxicity,
potential fertility

142 selected WASTES

criteria of classification

e.g., toxicity, aspect/smell,
fertility, ameliorating potential

27 selected WASTES

typology
of materials

characterisation: 14 parameters

11 MODEL WASTES

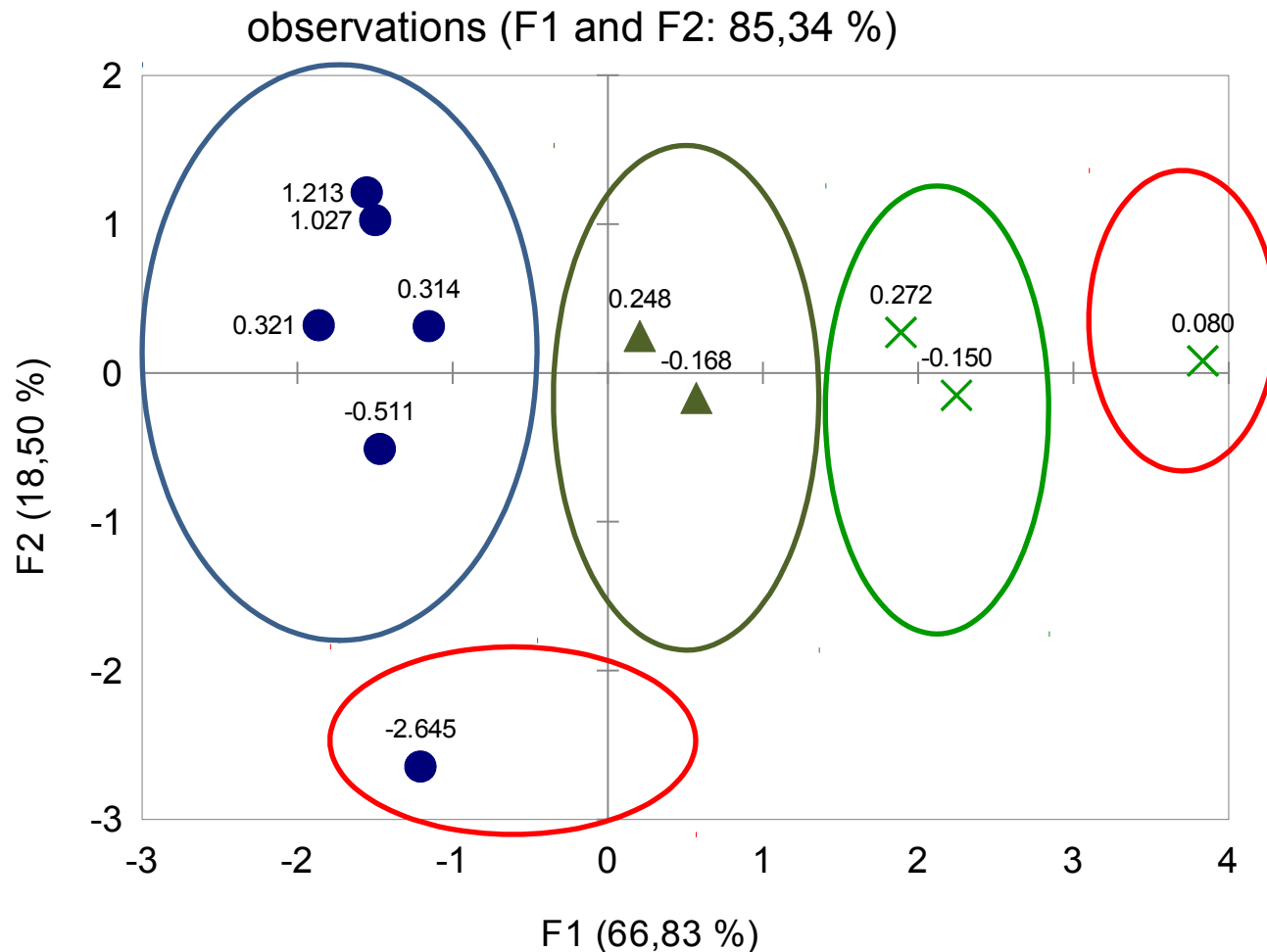
**representative
experimental models**



Fertility of selected parent technogenic materials

- Classical physico-chemical indicators

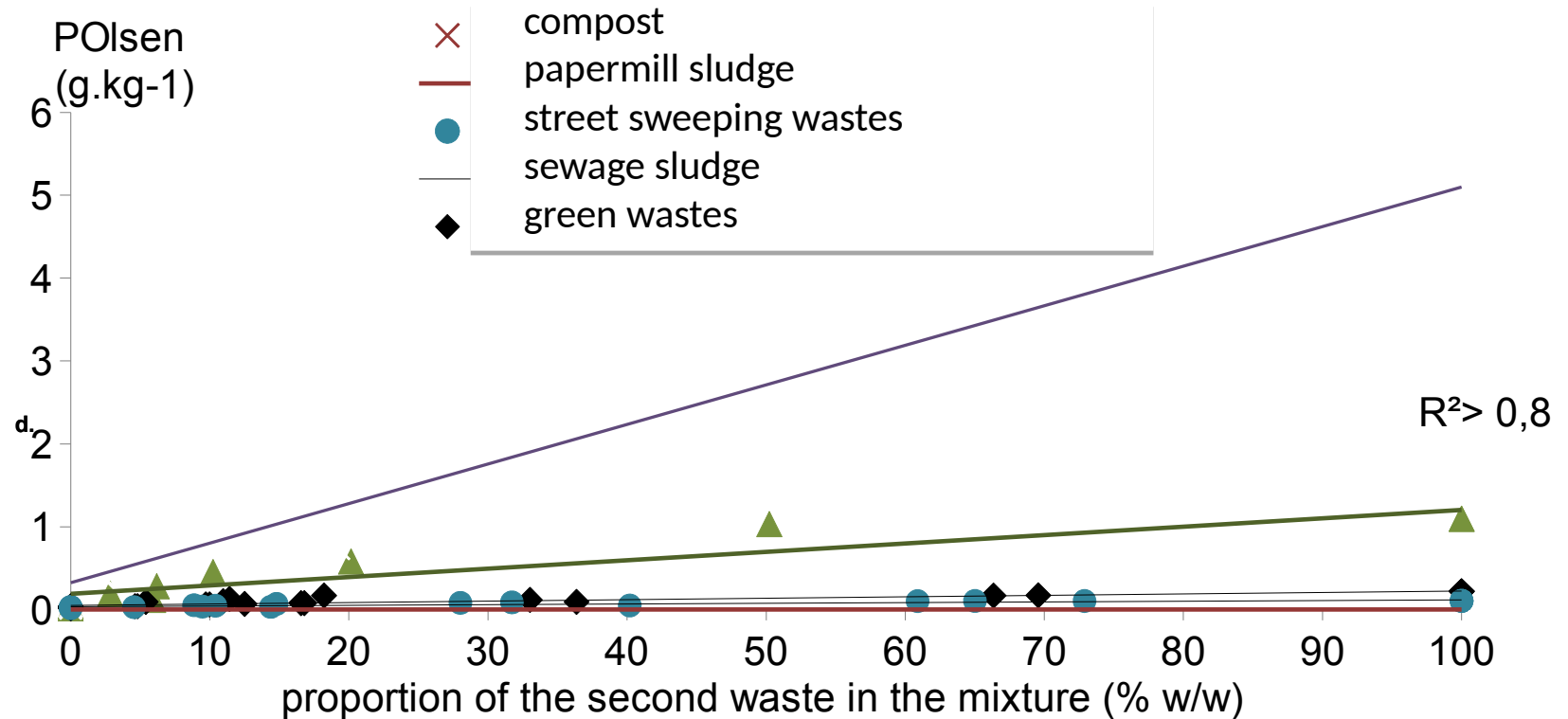
- Ctot, Ntot, CEC, POlsen, pH, CaCO₃, bulk density, water contents



- groups of wastes presenting potential fertility regarding physical or chemical properties

- mixing wastes is necessary in order to obtain « artificial growth media » presenting satisfactory features for plant growth

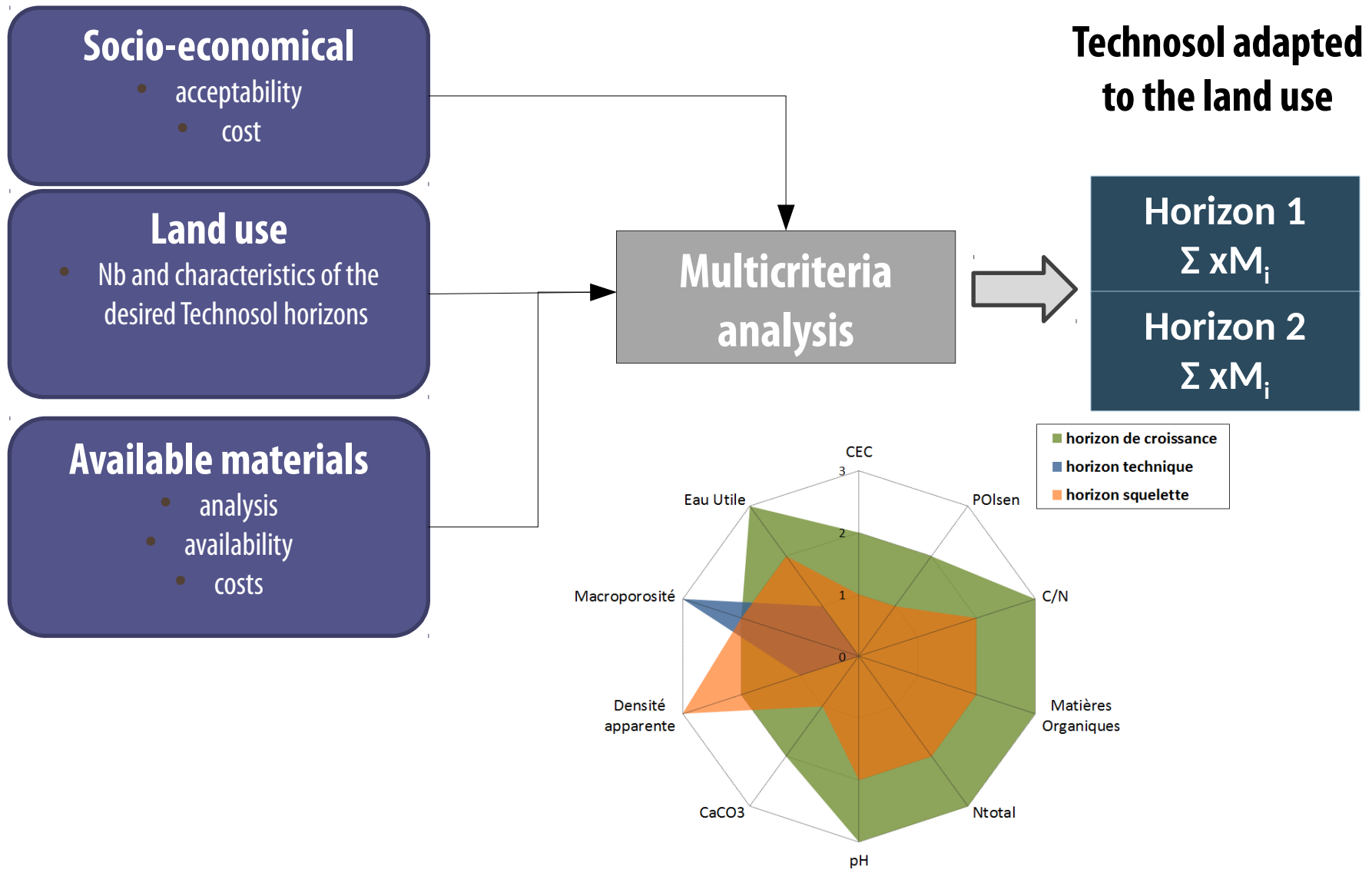
Dose-response curves with waste proportions: POlsen



- C_{tot}, POlsen, CEC modelled by regression curves
- fitness not systematically satisfactory
 - exploration of other models to describe the variation of the fertility of mixtures at different ratios

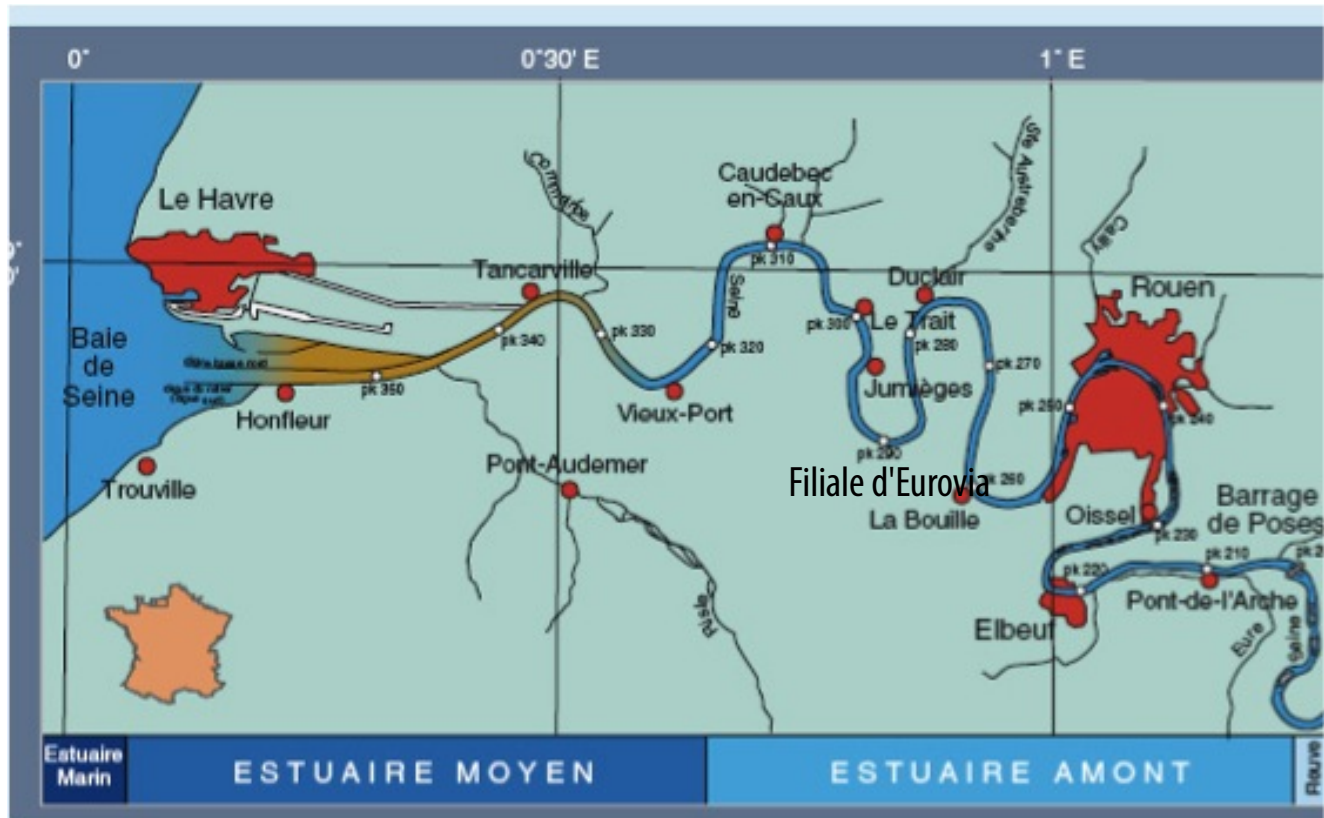
Adapt the formulation of the mixtures for a given land use

- Mixture model = basis for a Decision Support Tool



Example 1: use of dredging sediments to rehabilitate alluvial grasslands

- The Seine valley a highly anthropised catchment



Boigné *et al*, 2016

Example 1: use of dredging sediments to rehabilitate alluvial grasslands

- The idea
 - put the piles in the holes
 - Characterise the available wastes and by-products in the region
 - to mimic natural soils observed in the vicinity
 - Characterise nearby grasslands
 - Soil properties
 - Flora survey



Example 1: use of dredging sediments to rehabilitate alluvial grasslands

- Site evolution



Initial state



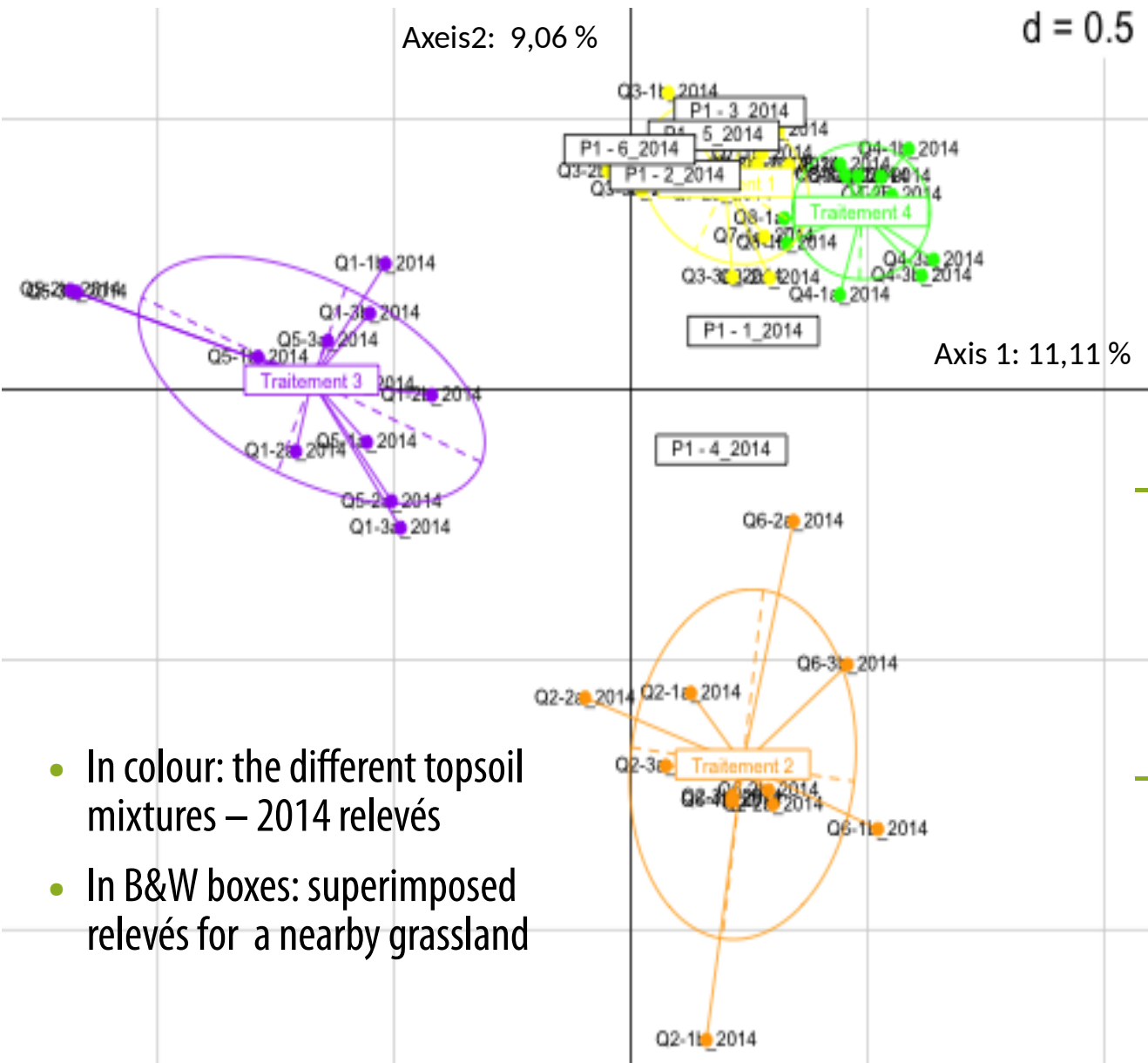
2013



2015

Firsts results

- Principal component analysis of vegetation relevés



- In colour: the different topsoil mixtures – 2014 relevés
- In B&W boxes: superimposed relevés for a nearby grassland

- Flora for yellow treatment is 53.23 % similar (Sorensen index) with the reference grassland
- Coming results on soil properties and microbiota

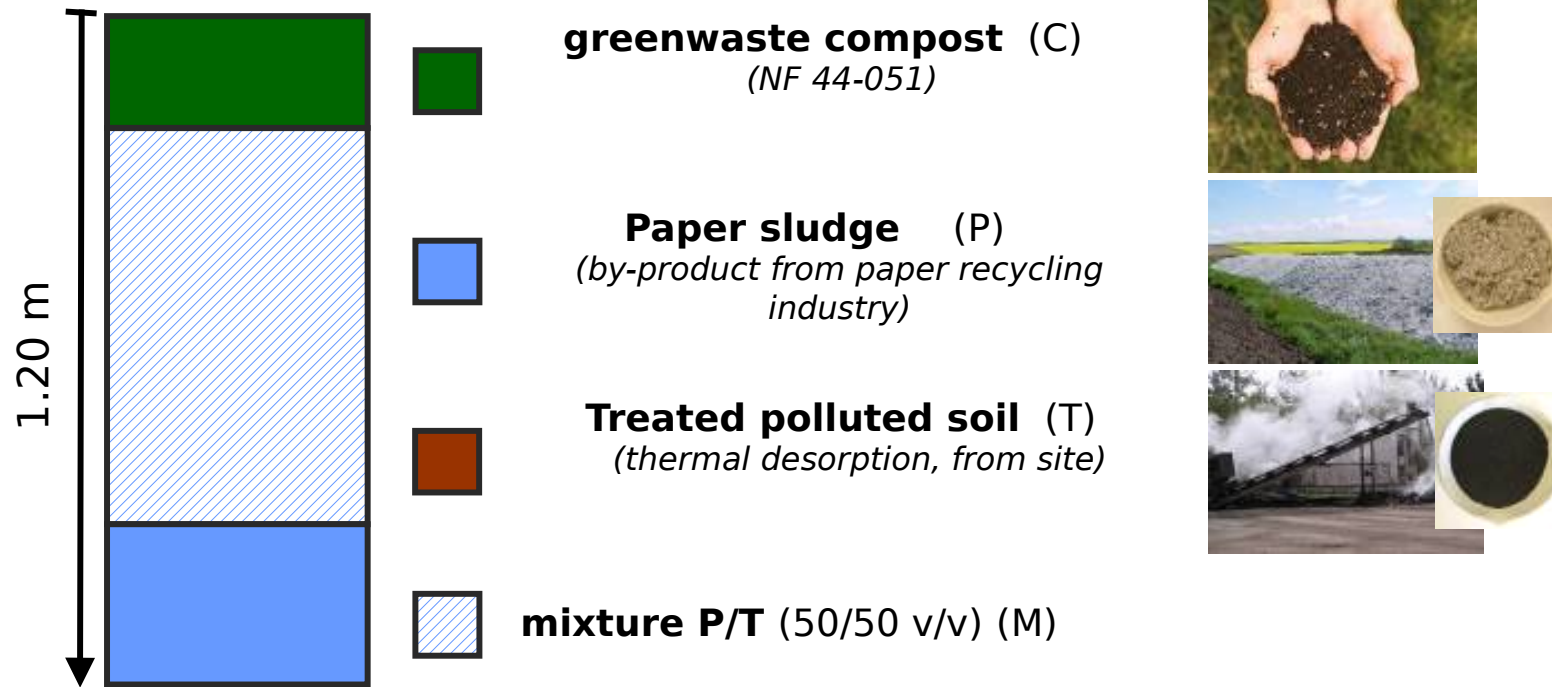
Example 2: soil construction on brownfield

- A former coking plant in Lorraine



Example 2: use of urban and industrial wastes and by-products for brownfield rehabilitation

- Selection of materials and mixture for Technosol construction



Example 2: soil construction on brownfield

- Site evolution



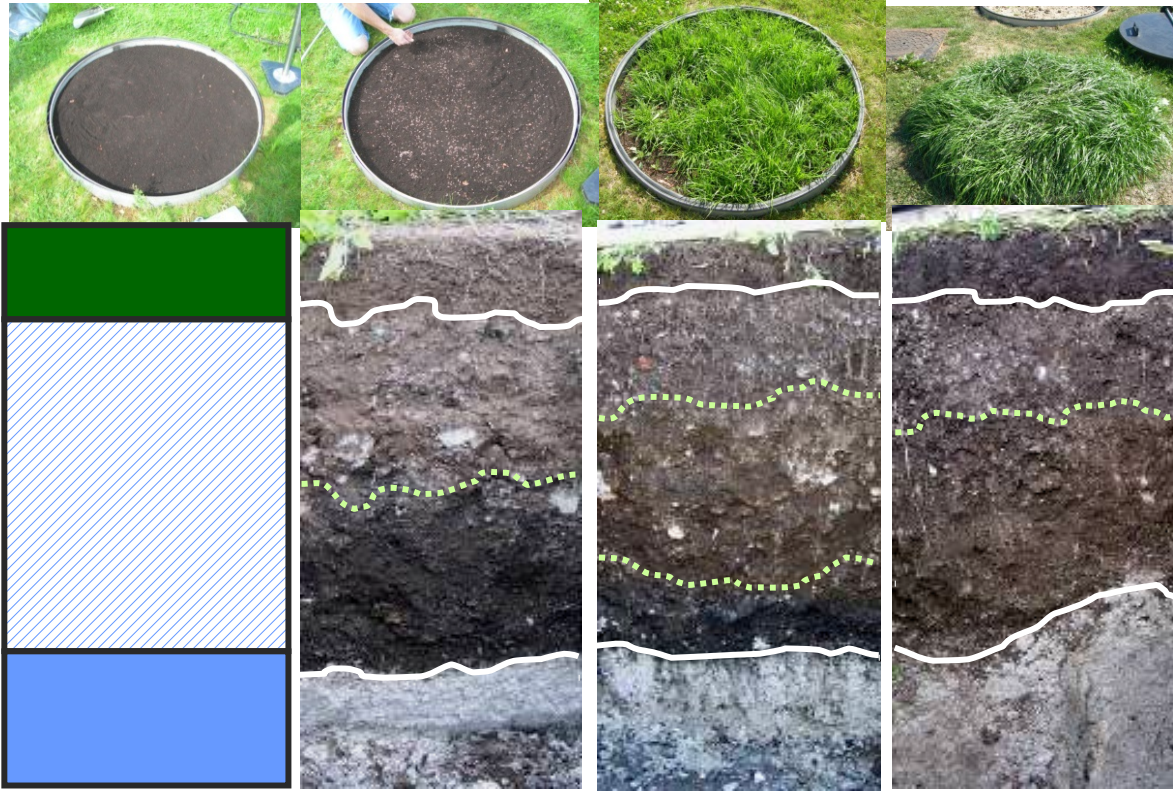
Séré et al. (2008) *J Soils Sediments* 8:130-136

Séré et al. (2010) *J Soils Sediments* 10:1246-1254

- progressive increase of the biomass production
- level of « provisioning service » equivalent to a natural soil/pasture

Example 2: use of urban and industrial wastes and by-products for brownfield rehabilitation

- Soil evolution



t_0
Spolic Garbic
Technosol
(*Calcaric*)

$t_{6 \text{ mois}}$
Spolic Garbic
Technosol
(*Calcaric*)

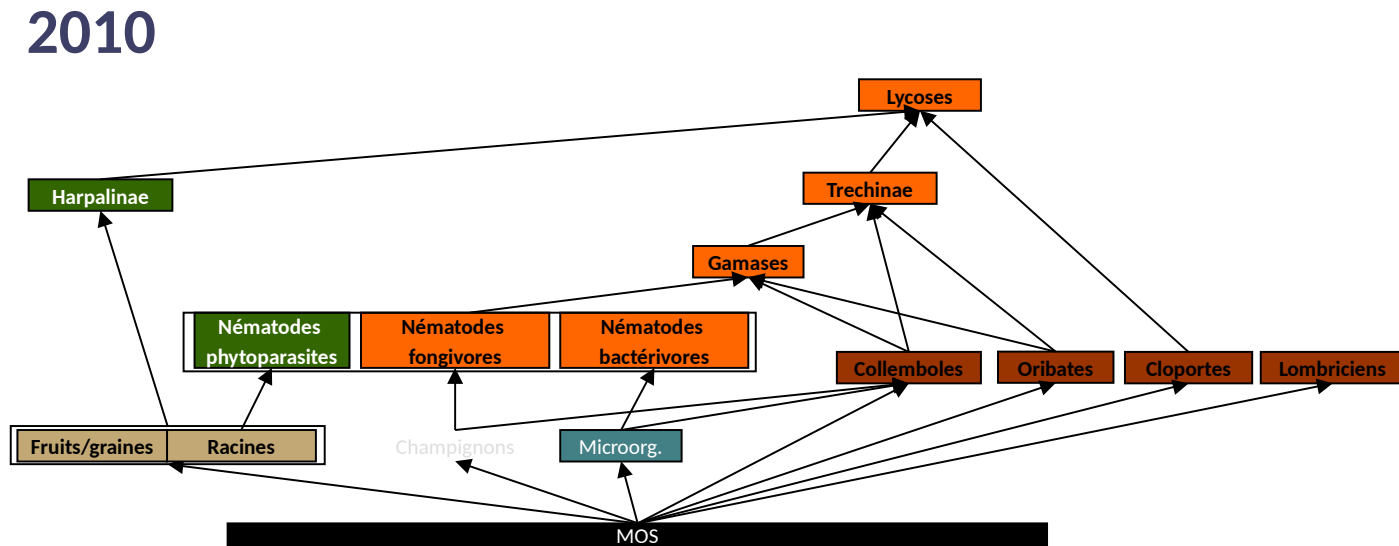
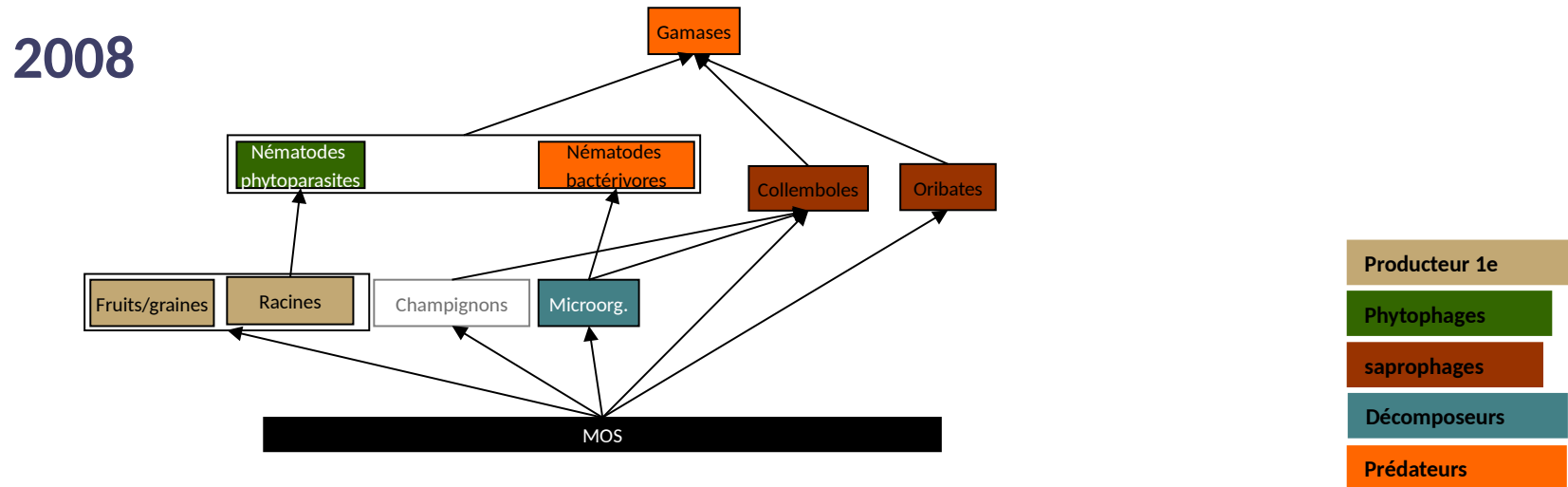
$t_{18 \text{ mois}}$
Spolic Garbic
Technosol
(*Calcaric, Reductic*)

$t_{30 \text{ mois}}$
Spolic Histic
Technosol
(*Calcaric*)



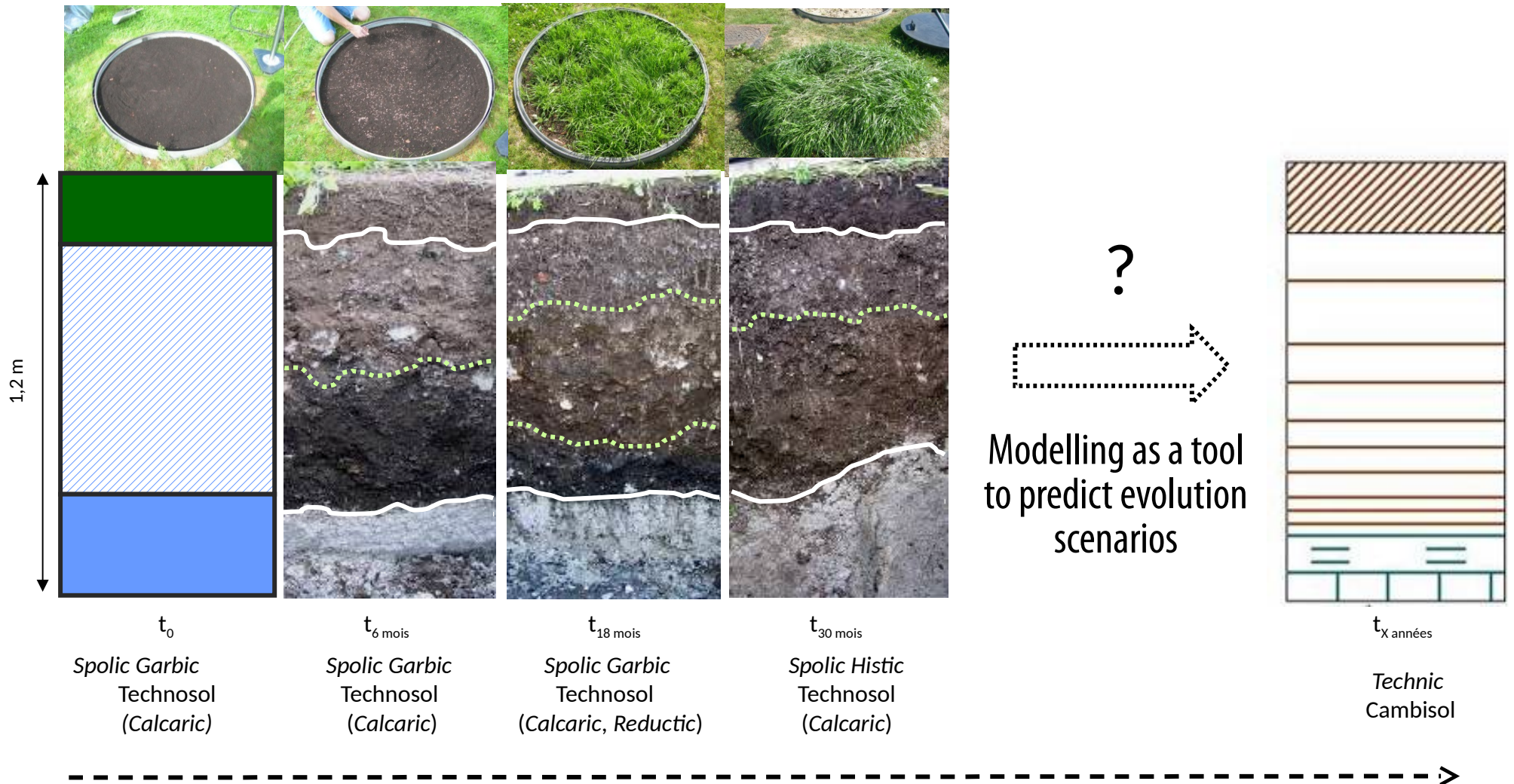
Example 2: use of urban and industrial wastes and by-products for brownfield rehabilitation

- Complexification of the food chain with time



Example 2: use of urban and industrial wastes and by-products for brownfield rehabilitation

- Fate of the system?

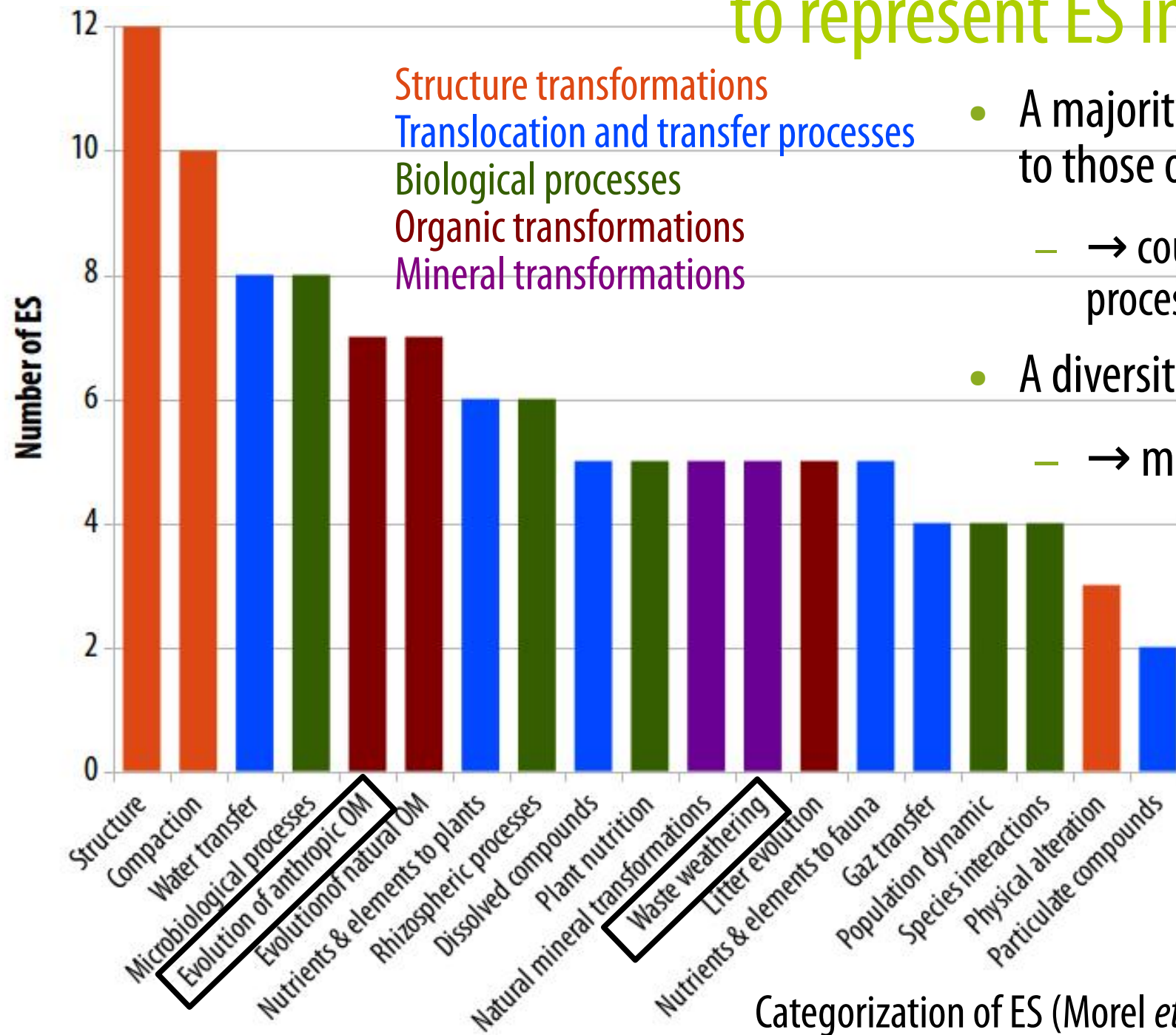


3- Modelling Technosol pedogenesis to predict its evolution

Outline of part 3

- Objective
 - State of the art in the development of the modeling of soil pedogenic processes influencing the support of ecosystem services in Technosols
- Materials and methods : mixed technical and conceptual analysis
 - Based on Morel *et al.* (2015, JSS) & Leguédouis *et al.* (2016, Geoderma)
 - Literature & concept review
 - Technical review of 18 existing models

Assessment of soil processes needed to represent ES in Technosols

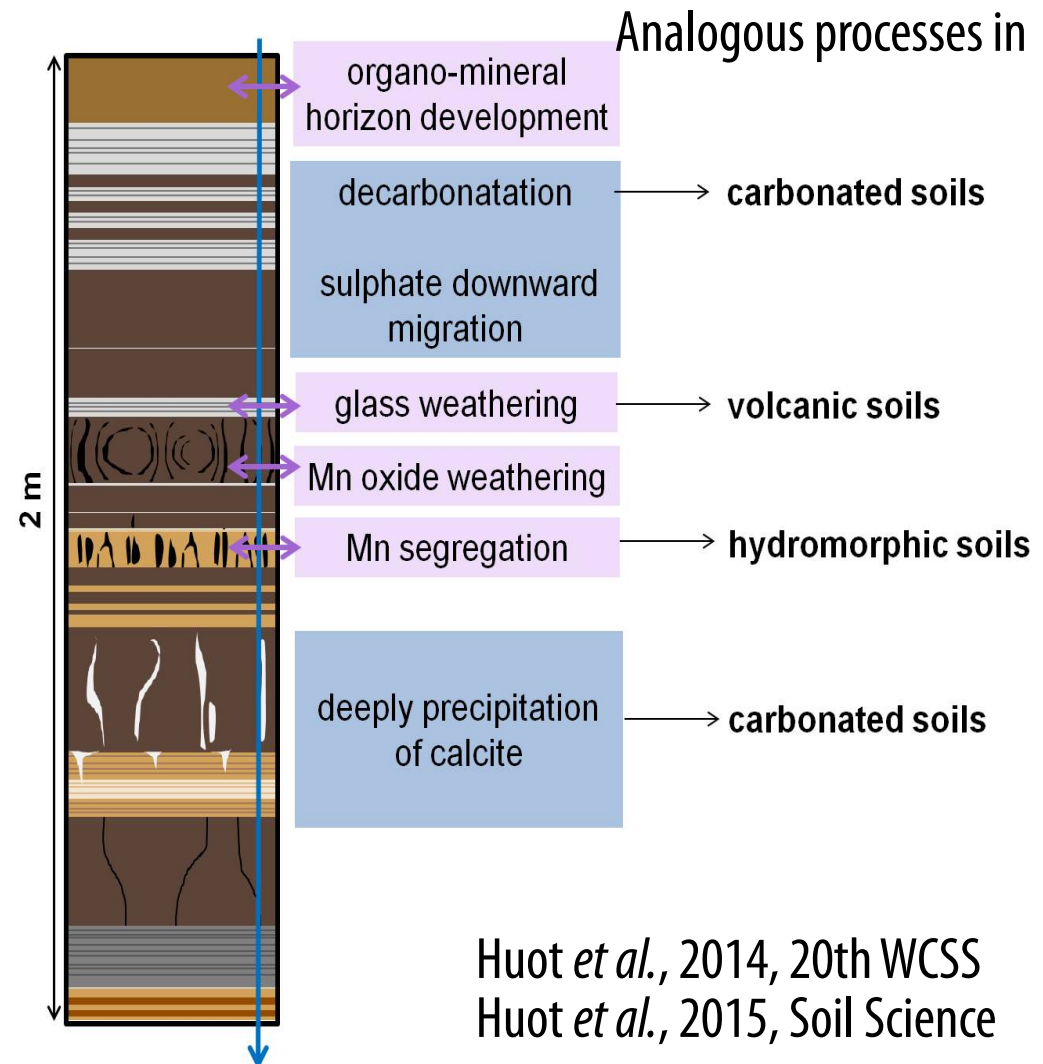


- A majority of processes similar to those of more natural soils
 - → coupling of existing process-based models
- A diversity of processes needed
 - → multi-process modeling

Coupling process-based models to represent ES in Technosols

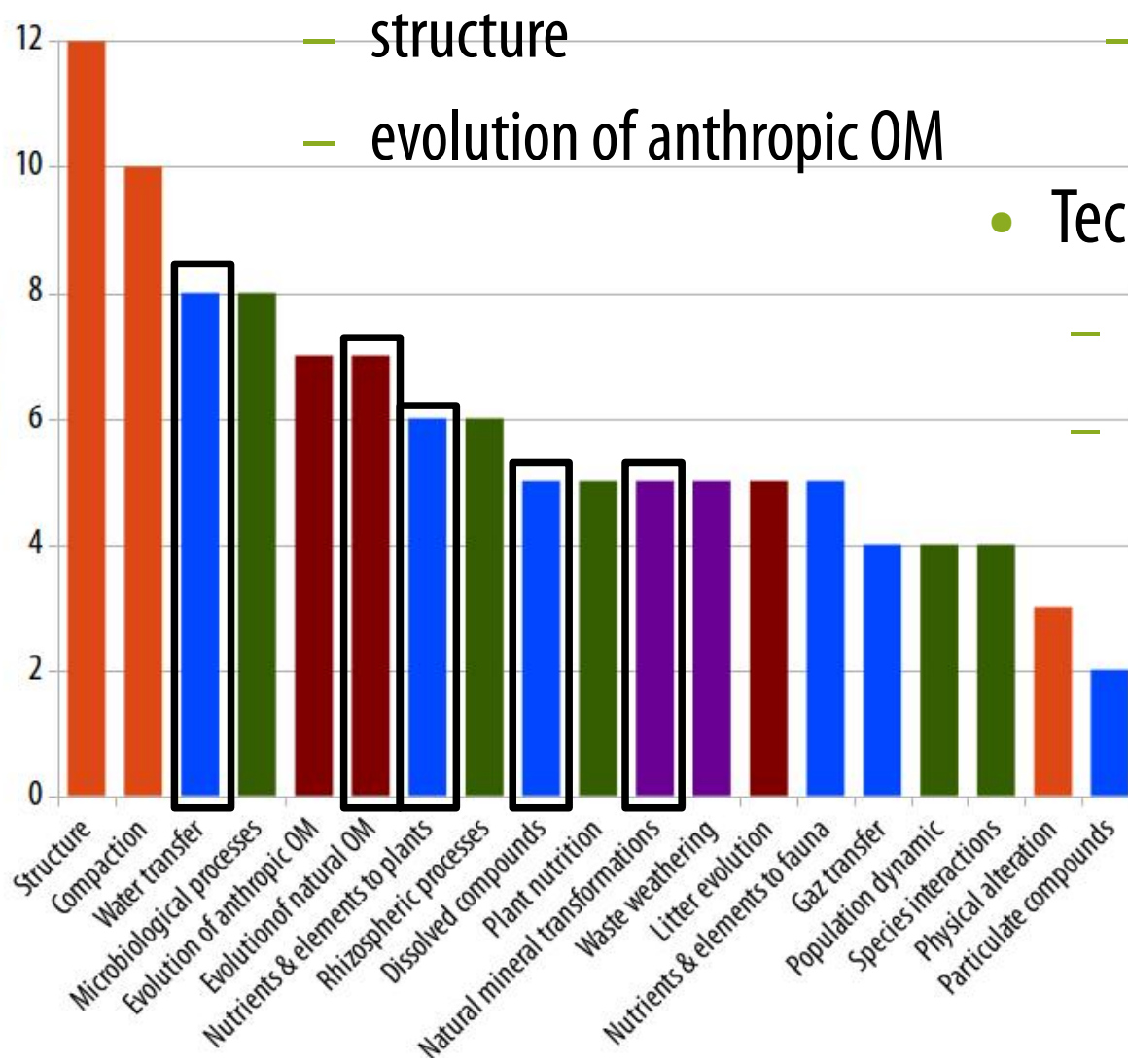
- Key issues and existing strengths
 - Occurrence of a wide variety of processes in Technosols
 - Unexpected combinations of processes
 - Process-based and multi-process modeling well developed
 - $\approx 83\%$
 - and $\approx 67\%$ of the analyzed models respectively
 - Modeled processes
 - 60% water transfer
 - 73% reactivity

Pedogenic processes observed in a Spolic Technosol



Coupling process-based models to represent ES in Technosols

- Developments needed in the modeling of processes related to:

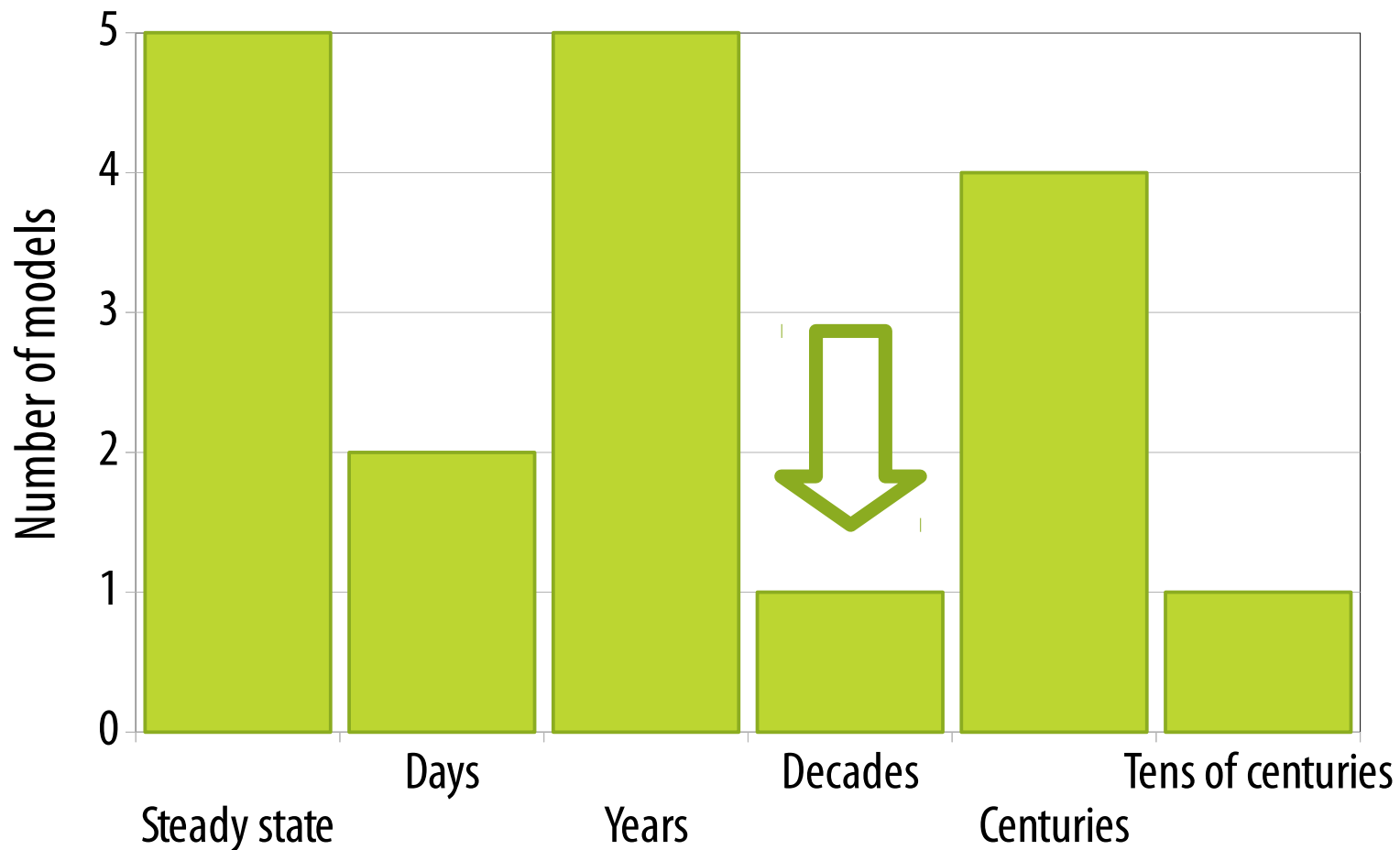


- Technical developments

- Interdisciplinary modelling team
- Coupling approach able to cope with the diversity of formalisms (e.g. differential equations, agent-based)
- Coupling platforms Sol Virtuel, Record
- VLE modelling environment/ DEVS
- Link with computing and numerical calculus domains

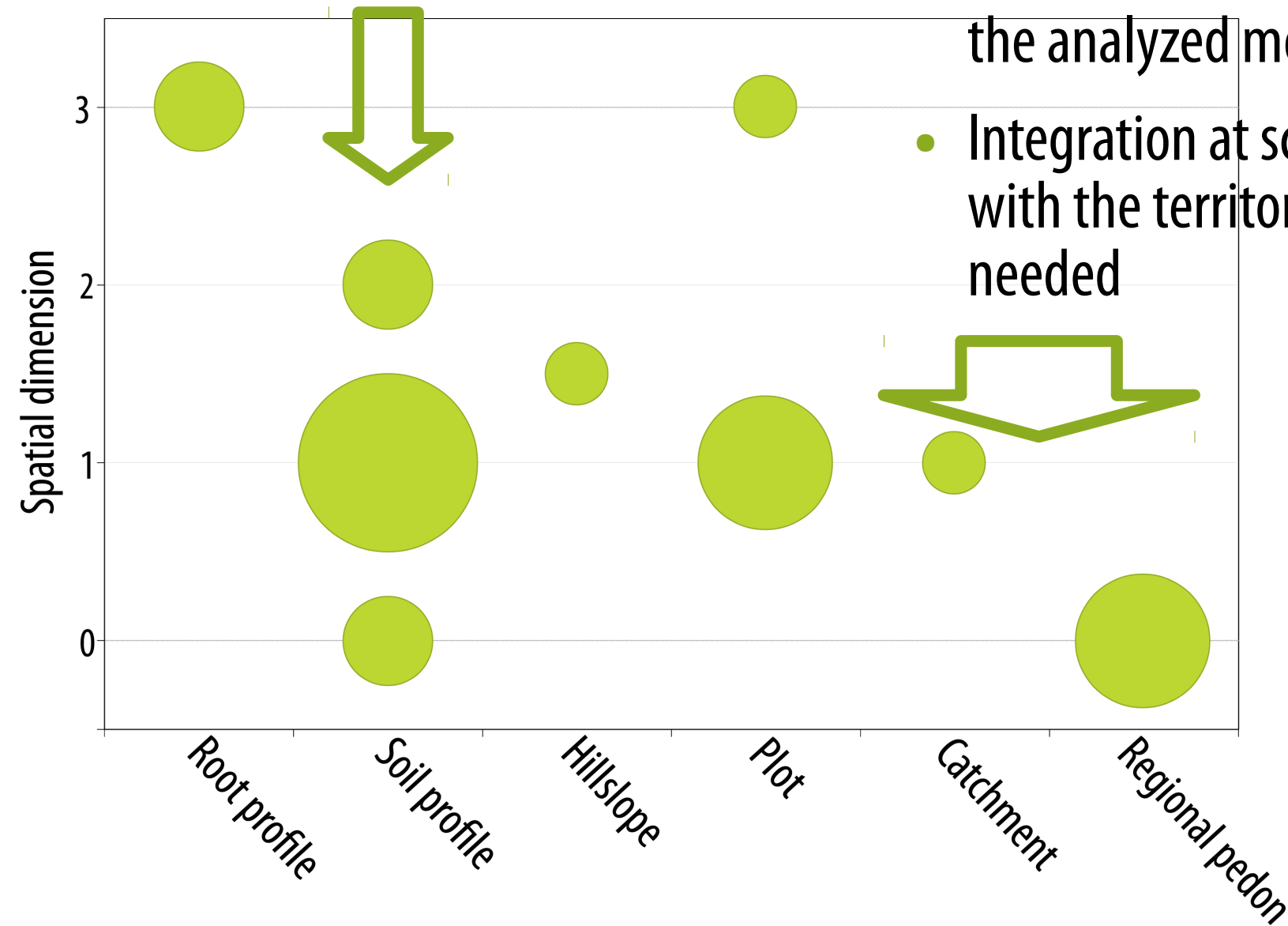
Time scale for the modelling of ES in Technosols

- Decade scale modelling is lacking to have a timing consistent with land-use planning



Spatial scale for the modelling of ES in Technosols

- Profile scale well developed in the analyzed models
- Integration at scale coherent with the territory level is needed



Conclusion on part 3

- Modeling ES in Technosols highlights the same needs as “natural” soils
 - development of biological and structure models
 - → interdisciplinarity
 - development of the coupling of process-based models
 - → ongoing interactions with computing sciences, numerical calculus, and statistics
 - need of decade and territory scale models
 - → link with economical and social sciences
- Specific features for Technosols
 - calibration for the unusual conditions found in Technosols
 - integration of the peculiar chemical and physical properties of technogenic materials