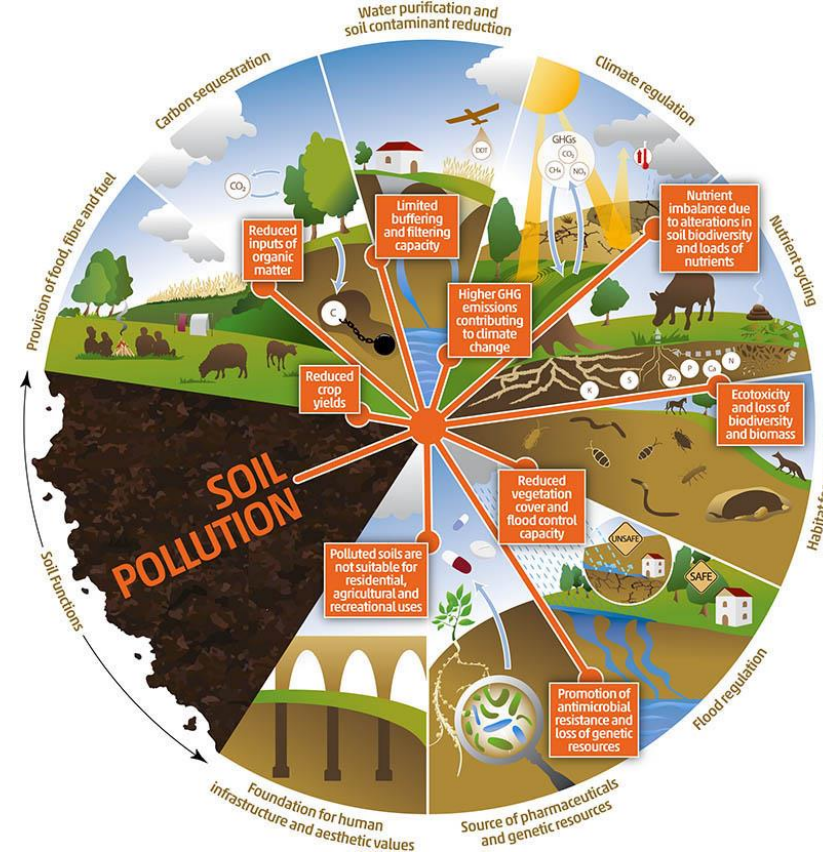


SOILPROM

Developing sustainable solutions for soil pollution

Modelling of pollution impact on soil ecosystem services: SOILPROM approach and example use case



<https://doi.org/10.4060/cb4894en>



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101156589.

Jakub Hofman

MUNI | RECETOX

Ecosystem services (ES) in SOILPROM

→ one of the main goals



01-09-2024

31-08-2028

SOILPROM

Developing sustainable solutions for soil pollution

Deliver **upgraded and integrated models for pollutant transport and fate that assess the impact of soil pollution on soil functions and related ES**



SOILPROM



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101156589.

SOILPROM planned results

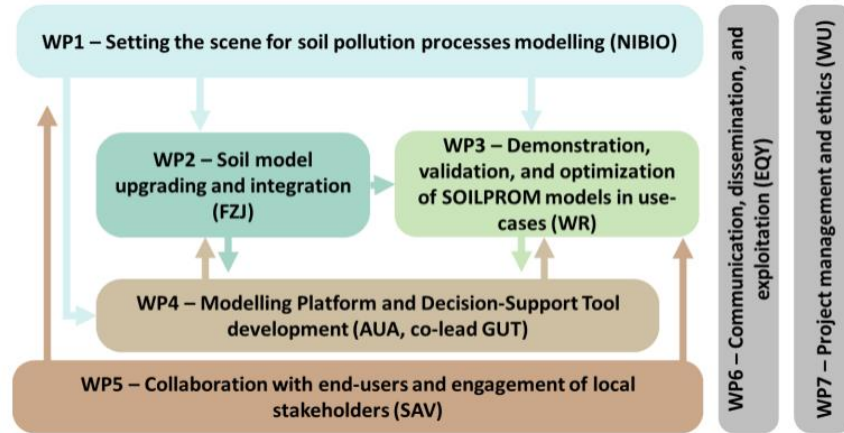


Figure 9: SOILPROM overall WP structure

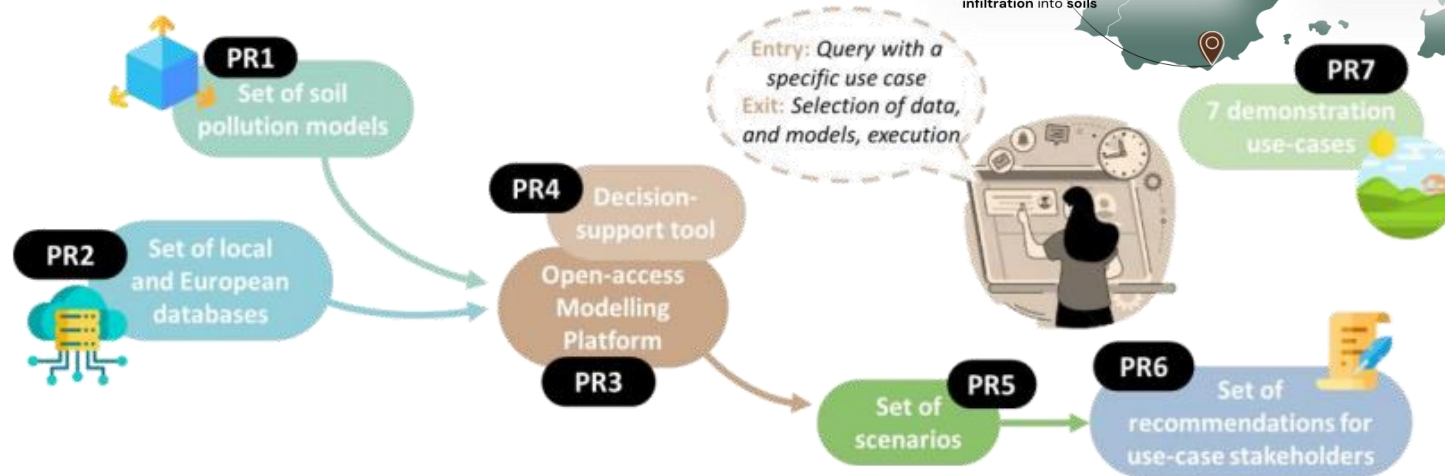
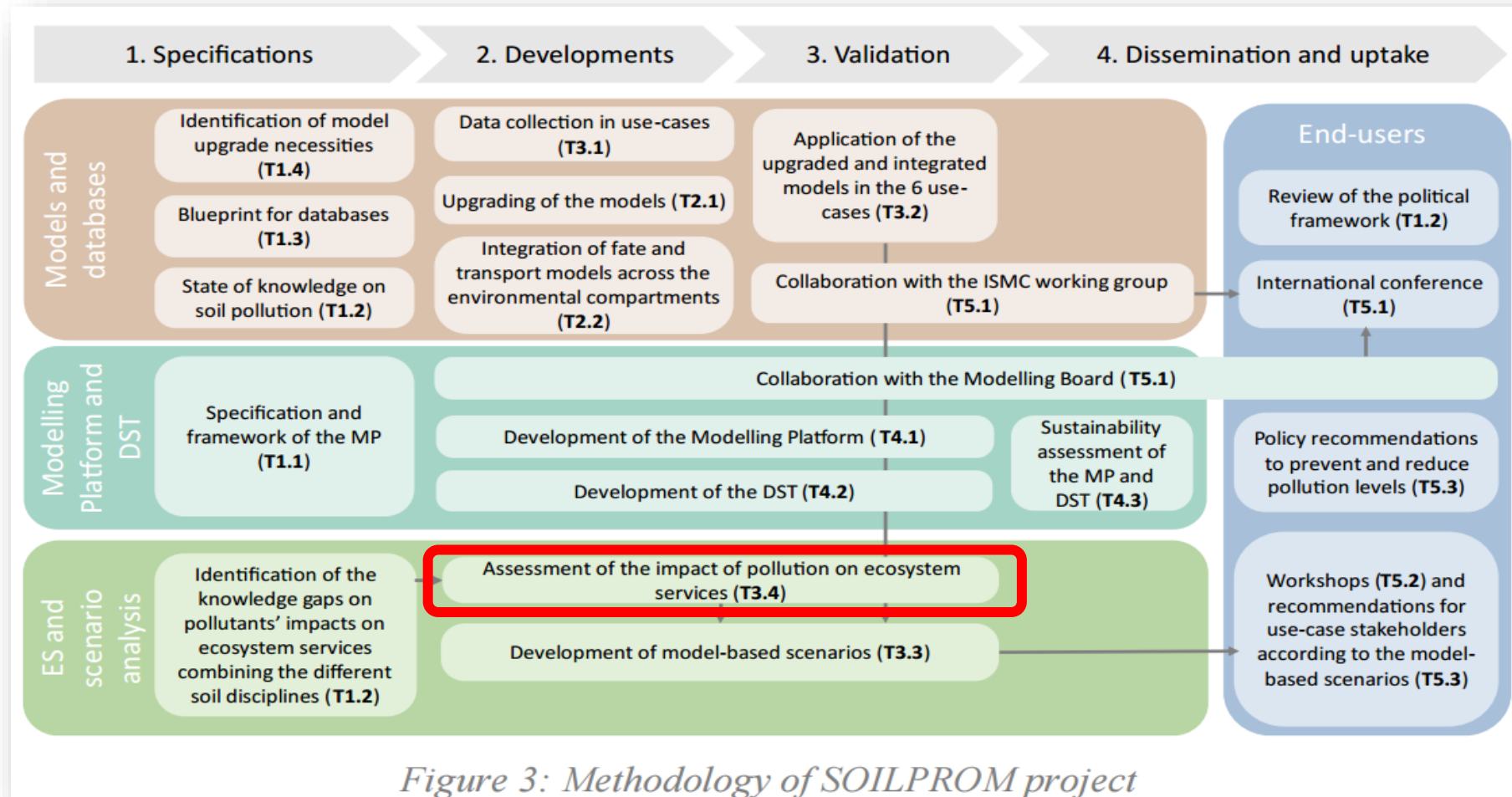


Figure 1: SOILPROM's Project Results



- The project is dominated by environmental-fate modelling: soil / water, soil / air ...

SOILPROM WPs and Ts



- The project is dominated by environmental-fate modelling
- **Impact on ES: one task starting 2/2027 and running for 16M**



SOILPROM

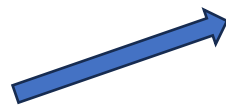


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Ecosystem services (ES) in SOILPROM → TASK 3.4

01-03-2027

31-08-2028



PHISHES complementarity ? PHISHES more water?

Impact of pollutants on **SOIL** processes, functions, and related ES in use-cases

Leader: MU – Participants: WU, WR, FZJ, UPCT, NIBIO, VITO – M30-M46

- **quantitatively assess the impact of soil pollution on ES**
- link T1.2 results to **critical threshold levels** of pollutant concentrations - a **methodology with mathematical equations**
- **methodology workshops** with all partners to discuss parameters to be used for the mathematical equation
- **use-case** leaders will assess the ES first in the current status and then in simulation scenarios

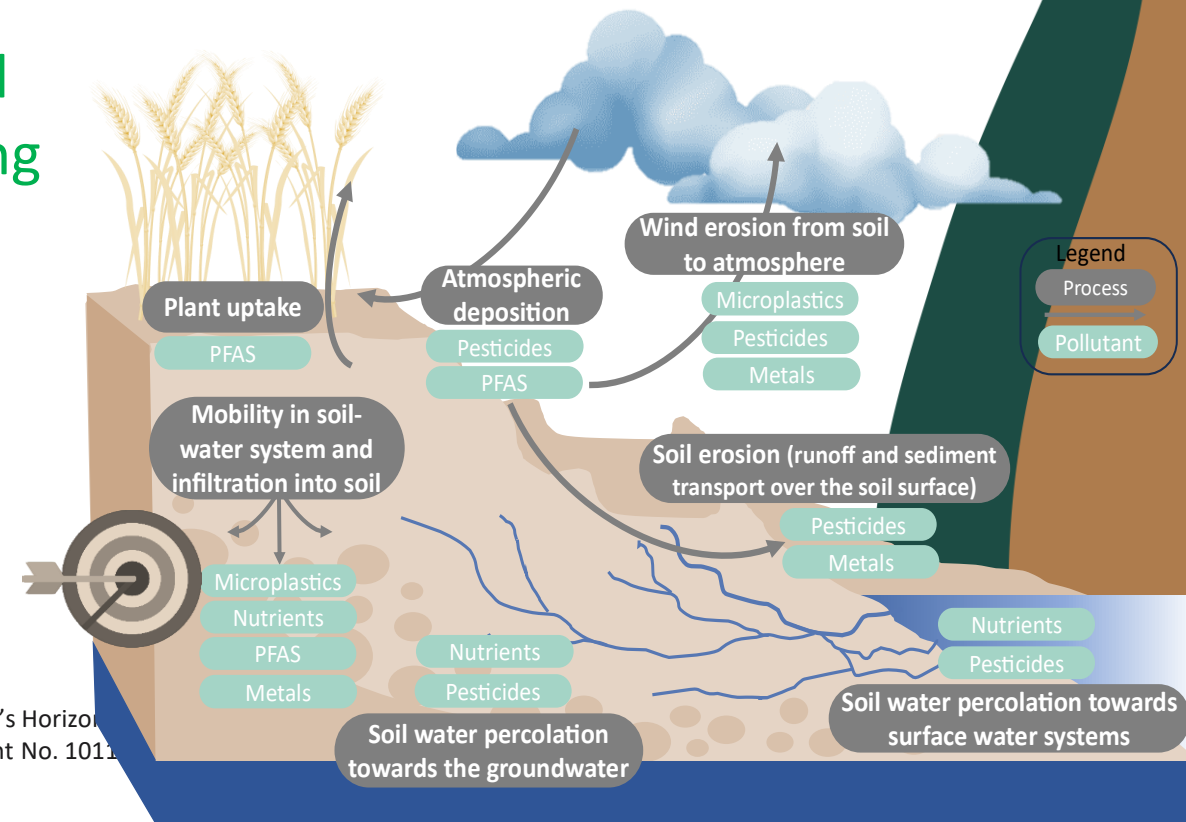
Two scenarios identified in SOILPROM use-cases

Scenario A (our focus)



PHISHES complementarity ? PHISHES more water?

- Soil is „receptor“ - pollutant stays in soil and damages soil biota / functions
- Fits the EU Soil Mission perfectly
- Soil ES impact is mainly driven by impact on soil biota
- Soil ES assessment can follow Environmental Risk Assessment (ERA) framework: comparing exposure (PEC) against biological effect thresholds (PNEC)
- Relevant use cases: 1 (MPs), 2 (MPs), 4 (pesticides), 6 (PFAS), 7 (metals).
Semi-relevant: 3 + 5 (pesticides)



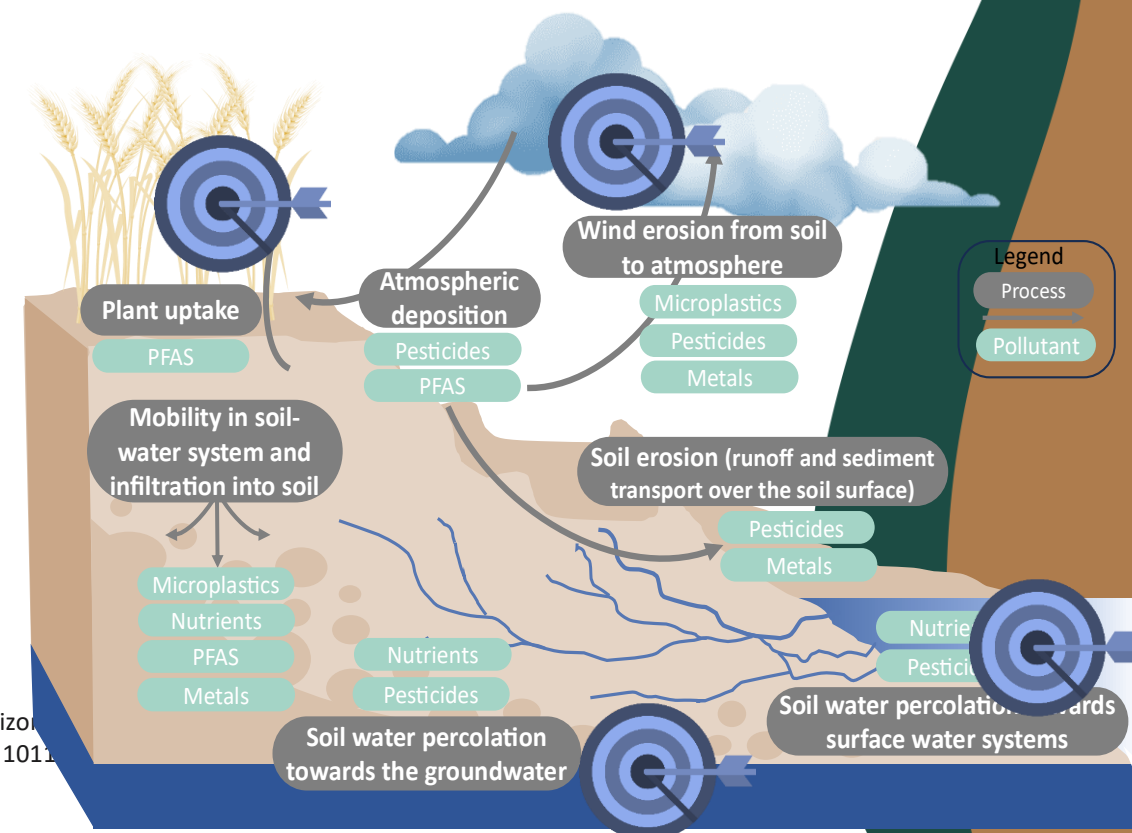
Two scenarios identified in SOILPROM use-cases

Scenario B

- Soil is „transfer pathway“ - pollutant moves through soil to water / air
- Soil functions (e.g., filtering) act as regulators.
- Impact is external (aquatic ecotox, human health via water).
- Focus shift: „soil health“ → „soil capacity“ to filter / buffer for water / air (+ to contaminate water / air)
- Impact driven by levels of transported pollutants in target compartments
- Assessment based on environmental fate modelling of concentrations in target compartments + comparison to limits (regulatory or derived from risk assessment).
- Relevant use-cases: 3 (pesticides/runoff), 5 (pesticides/GW), 8 & 9 (nutrients/runoff+GW)

SOILPROM promised to assess leaching and redistribution potentials (the soil-side export terms) but NOT the impact at the receiving end !

→ closer to  PHISHES ?



SOILPROM – dominantly scenario A ! ... How?

Ecological risk assessment based modelling of SES impact

Faber et al. (2021) <https://doi.org/10.1016/j.scitotenv.2021.146409>

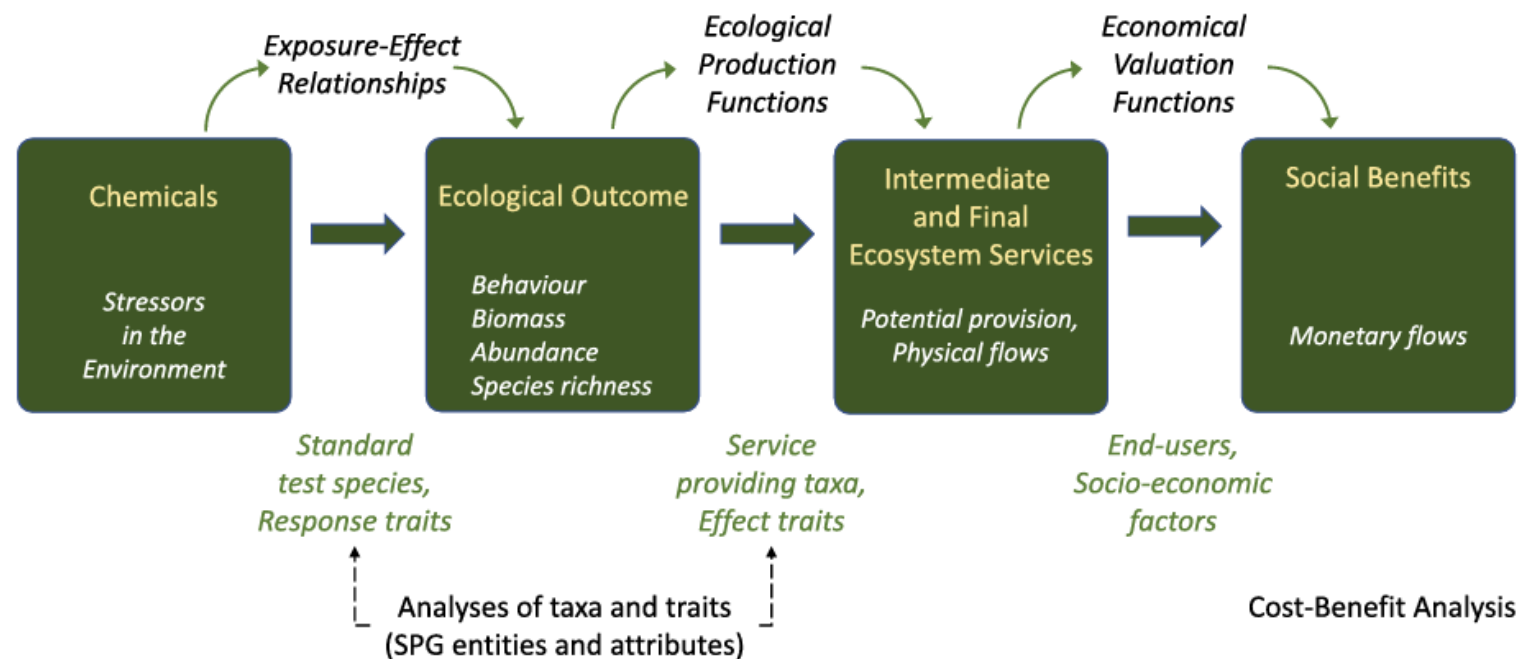
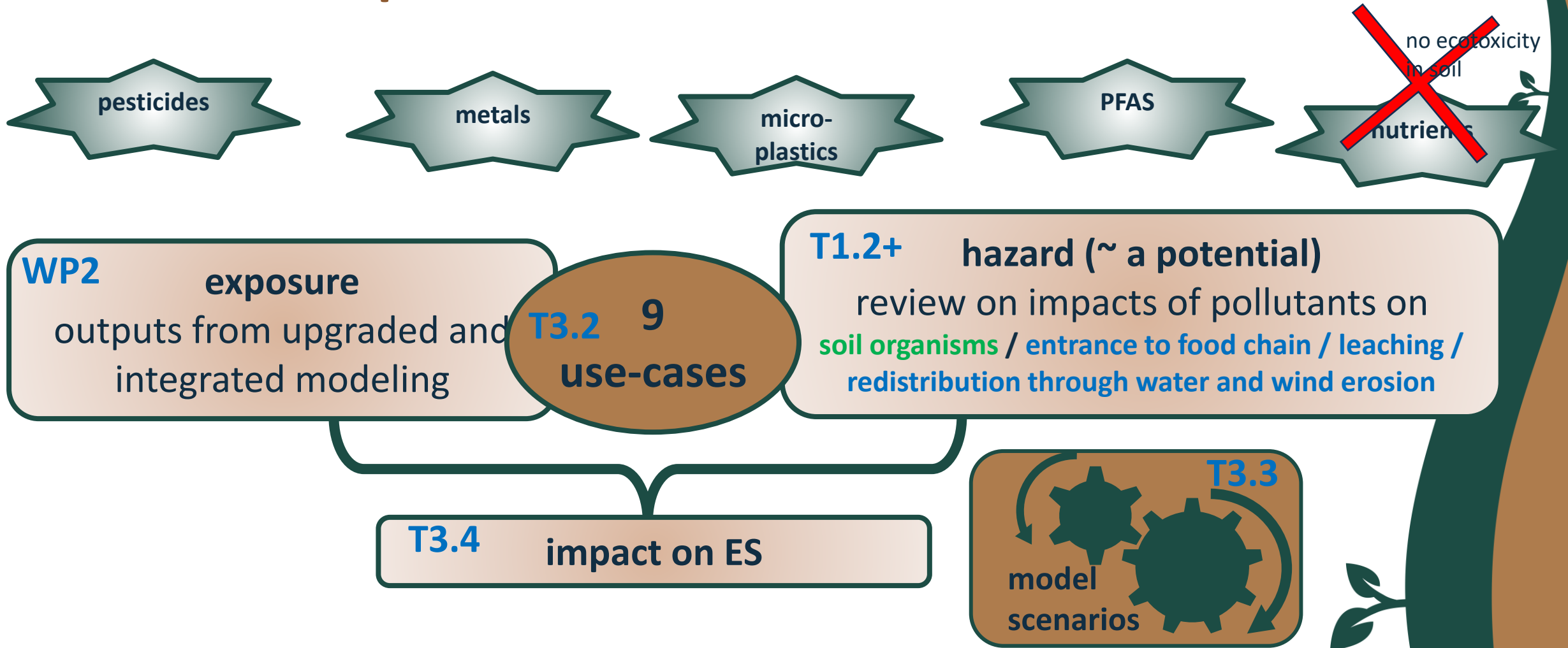


Fig. 1. The translation of effect data from standardised ecotoxicological testing for ES impact assessment using ecotoxicological exposure-effect relationships and ecological production functions based on response traits and functional traits (also called 'effect traits') respectively. EPFs quantify potential provision of intermediate or final services, and socio-economic factors determine actual flows of services 'physical flows' and benefits 'monetary flows'.

Ecological risk assessment based modelling of soil ES impact



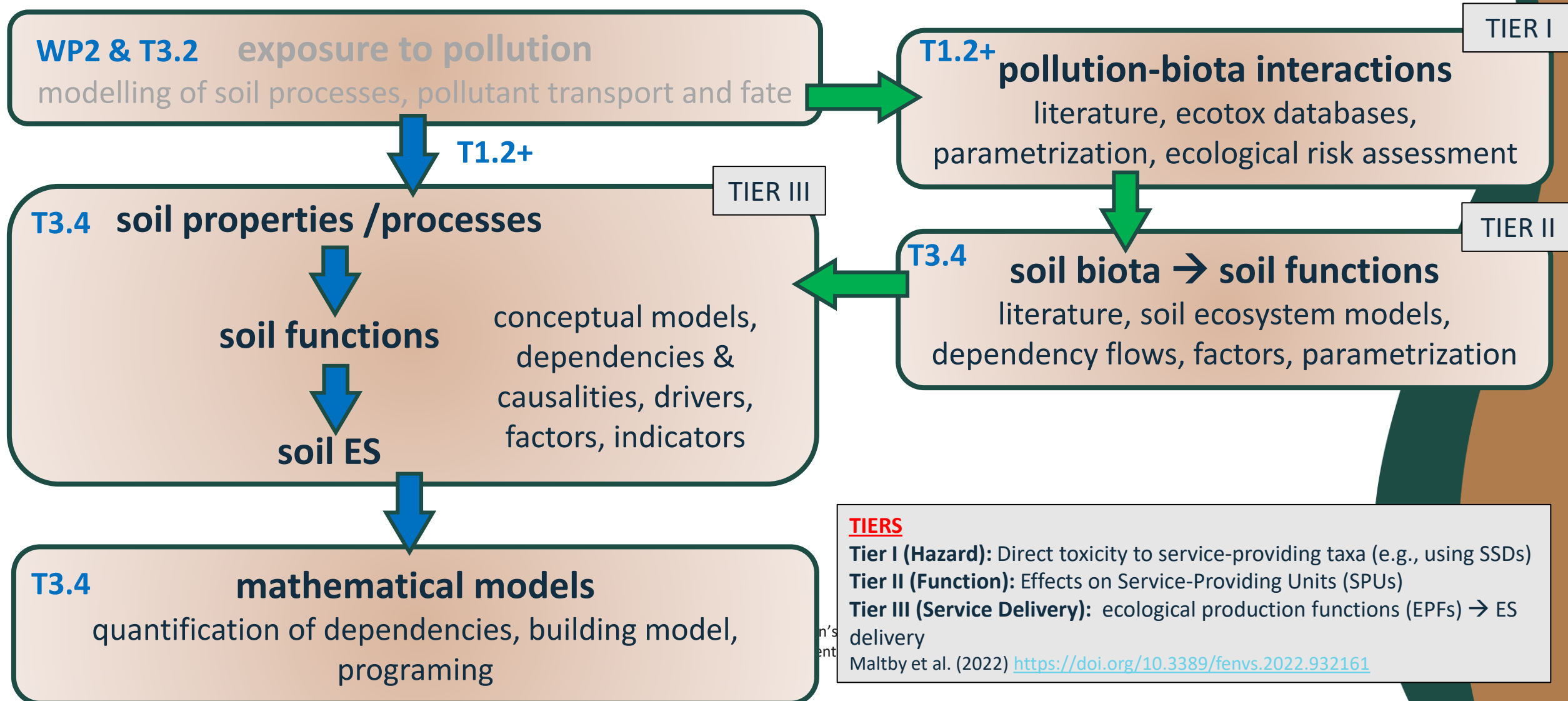
Ecological risk assessment based modelling of soil ES impact

ES based ERA:

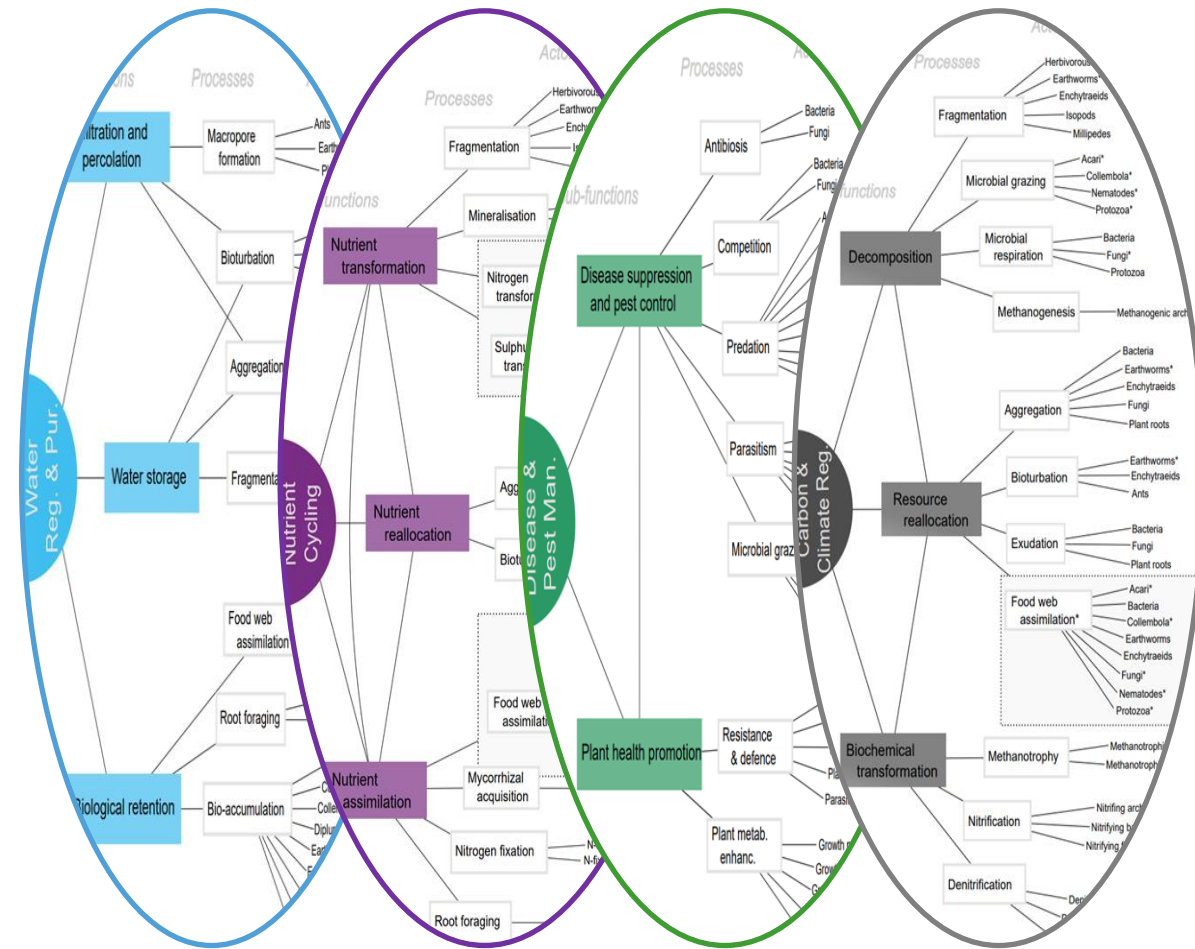
Devos et al. (2019) <https://doi.org/10.2903/j.efsa.2019.e170705>

Faber et al. (2021) <https://doi.org/10.1016/j.scitotenv.2021.146409>

complex model - „a pipeline“ will be needed

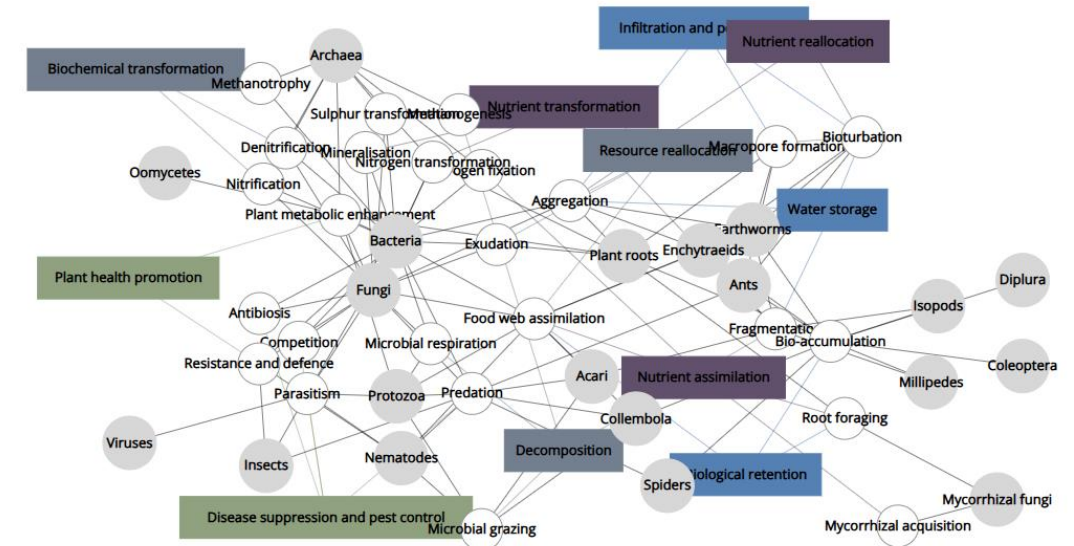


Tier I → Tier II ... How ?

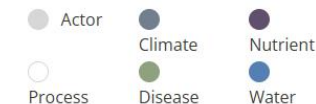


Soil Health BENCHMARKS

<https://soilhealthbenchmarks.eu>



<https://biosisplatform.eu/services/soil-biota-and-functions>



Creamer et al. (2022): <https://doi.org/10.1016/J.SOILBIO.2022.108561>

Vazquez et al. (2025) <https://doi.org/10.19103/AS.2025.0159.01>

Tier II → Tier III ... How?

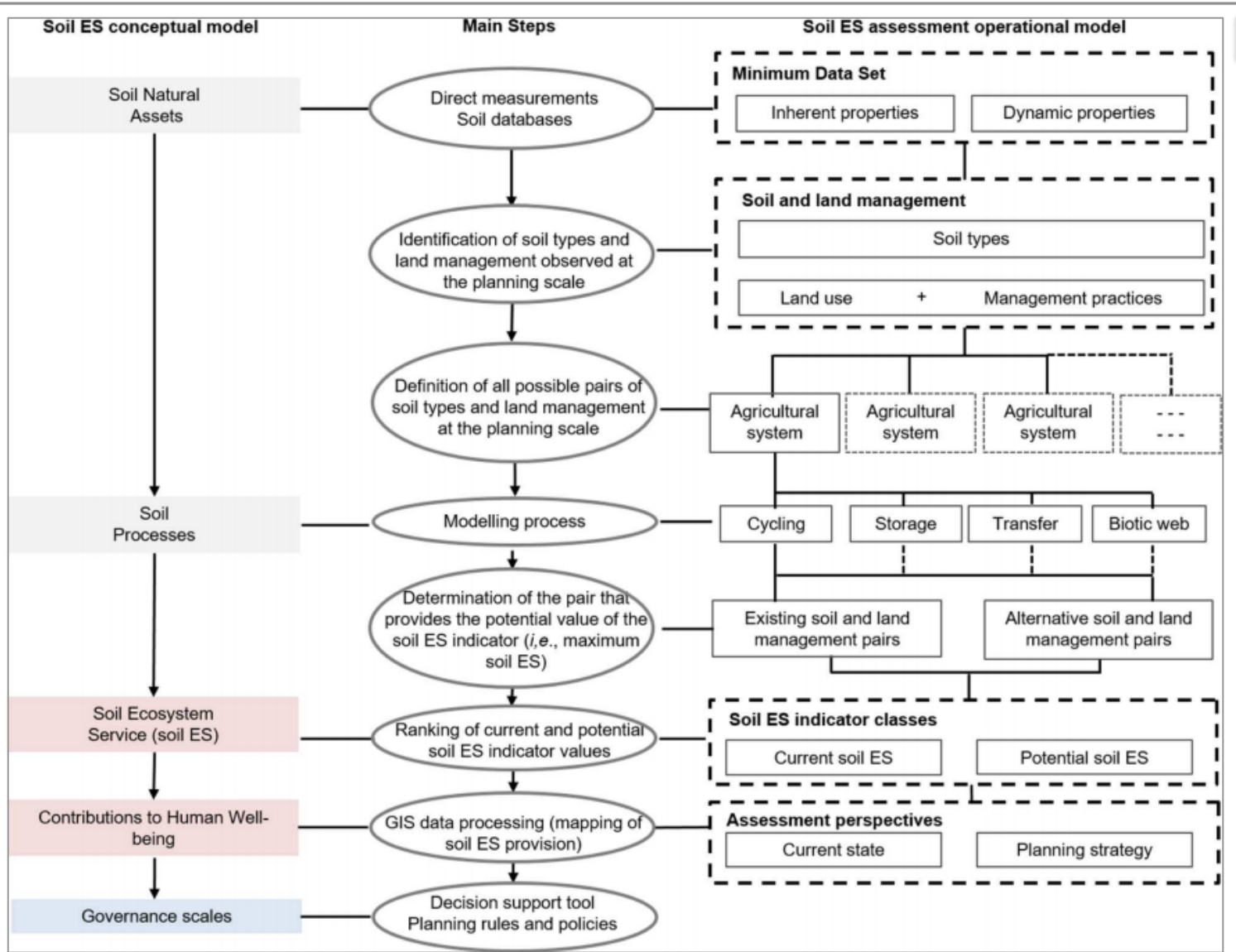
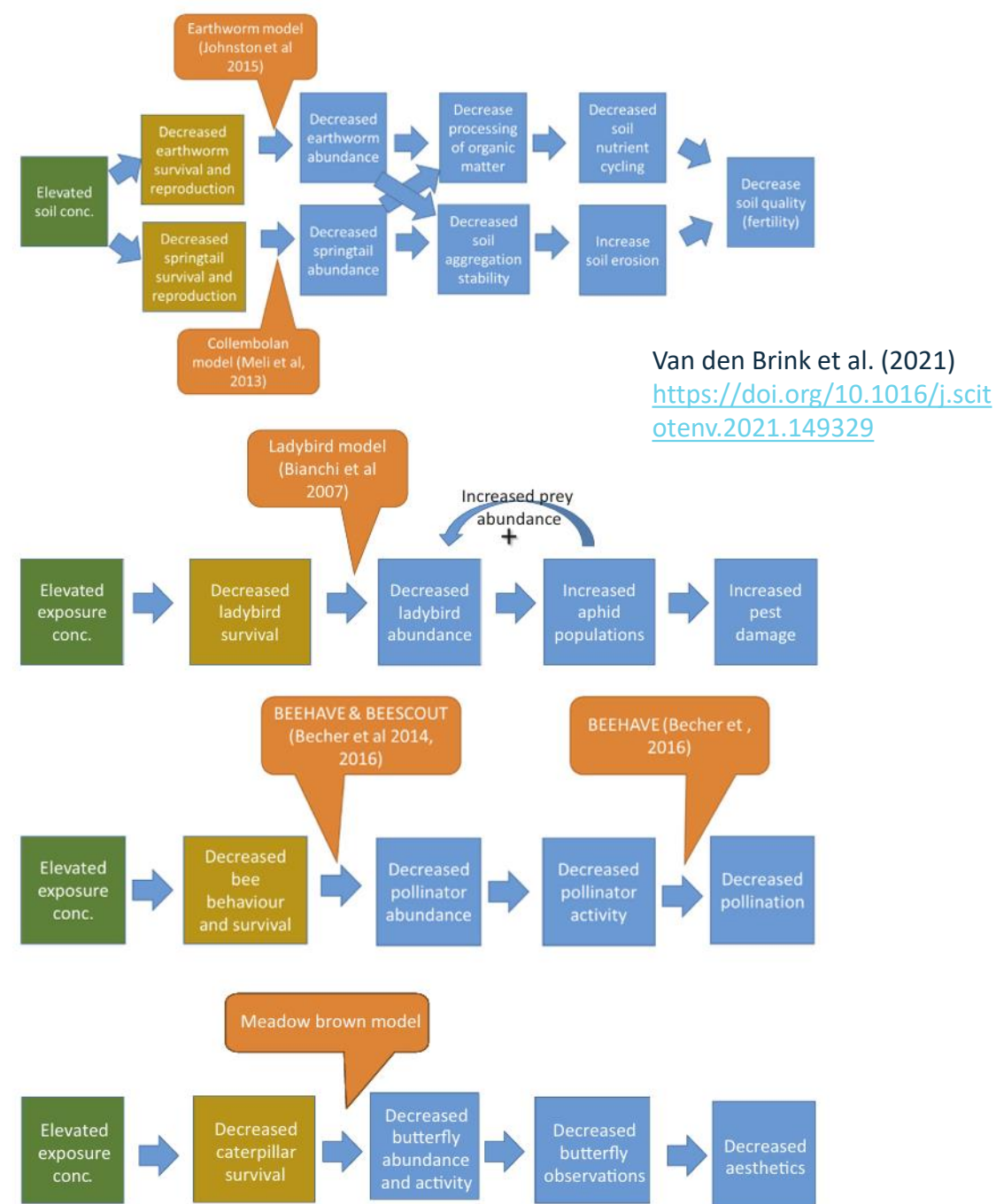


FIGURE 3 | Workflow of the operational model for assessing agricultural soil ecosystem services (ES).

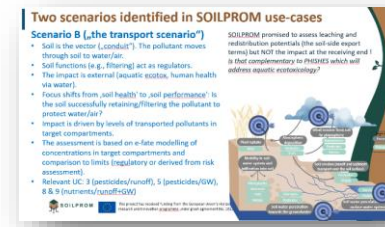
Soil ecosystem services literature
including ES valuation literature

Quantification ... ?

- searching for models, link by link
- connections
- approximations



Scenario B: Possible approach



 PHISHES collaboration?

- We will not model "impact" on water body itself (e.g., ecotoxicity, eutrophication ...) - Instead, we treat the soil output (leaching/runoff concentration) as endpoint:

$$\text{Exceedance ratio} = C_{\text{output}} / C_{\text{limit}}$$

- If $IQ > 1$, load of pollutants into soil exceeded its capacity of „water filtration/retention “ (=ES)
- If $IQ < 1$, load of pollutants into soil is within its capacity of „water filtration/retention “ (=ES)
- **C_{limit} definition - TBD**
- We need to compile the specific regulatory limits for the relevant water bodies (WFD EQS, Drinking Water Standards) for the specific regions (NL, DE, NO, PL)
- C_{limit} can also be risk-based: We may define safe concentrations in surface water from PNEC values for aquatic species. We may define safe concentrations in groundwater (drinking water) and air from human health risk assessment.

 PHISHES collaboration?

Open research questions we'd like to discuss

- going quantitative
- plug&plays between tiers
- bioavailability role at interface between exposure and Tier I
- hazard data (un)availability (especially higher tiers, life-history traits, functional traits, service-providing units → approximations needed, ecological modelling needed)
- gaps between endpoints sensitive at realistic concentrations (e.g. biomarkers) and service-providing taxa – AOPs can help?
- gaps between endpoints of service-providing taxa and service-providing units (populations, functional groups)
- setting critical thresholds
- multiple effect / thresholds mathematical algebra
- abiotic (indirect effects) of microplastics in soil



SOILPROM

Use case – Spain – Cartagena mining district



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101156589.



SOILPROM

Spain use case

Nazaret González
(UPCT)

SE Spain



Cartagena-La Unión Mining District, 50 km²

Primarily mined for Fe, Pb, Zn (**Cd, Mn, As, Cu...**).

Fe in **sulfides**, oxides, hydroxides, sulfates, carbonates, silicates.

Pb and Zn in **sulfides**, carbonates, sulfates, oxides.

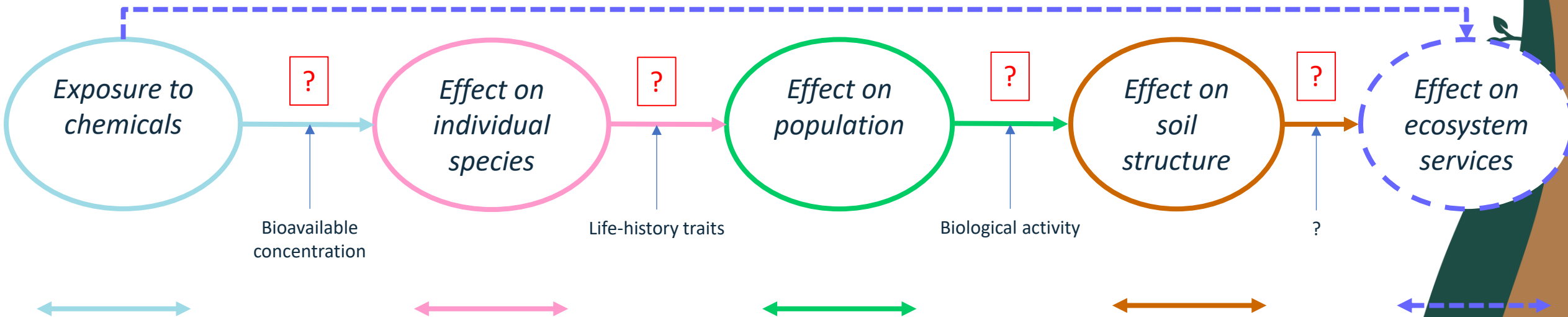


The last mine was closed in 1991. Millions of tons of mine waste remain in the area and the surroundings.

High-resolution data:
pore water metals, speciation,
physicochemical properties

Field data on metal concentrations and soil properties

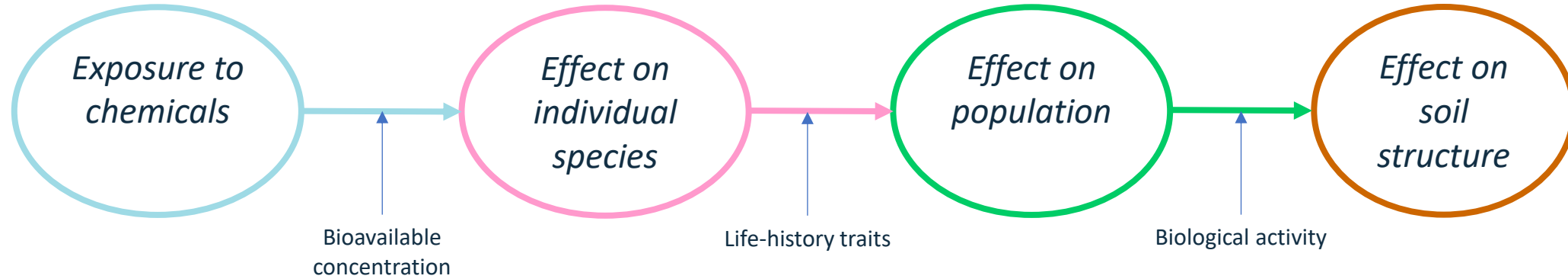
Linking soil biota activity exposed to chemicals to possible changes in soil functioning



Temporal scale: days, months, years, decades

Different pollutant groups may need adapting causal cascade based on available evidence

Linking soil biota activity exposed to chemicals to possible changes in soil functioning



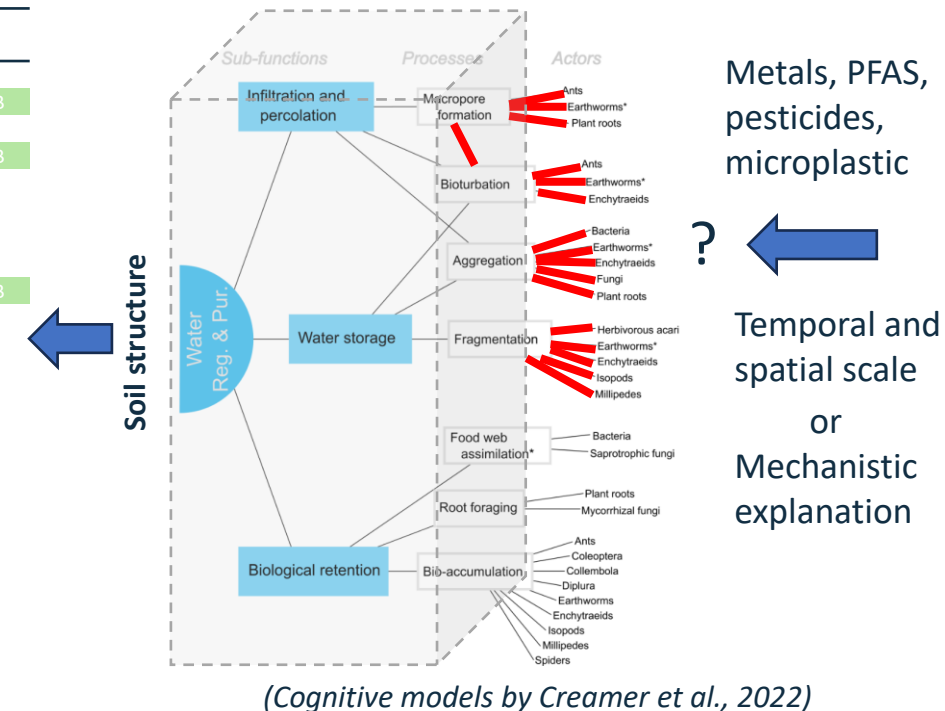
Incorporating process knowledge in modelling changes in soil structure

Need for simple framework to:

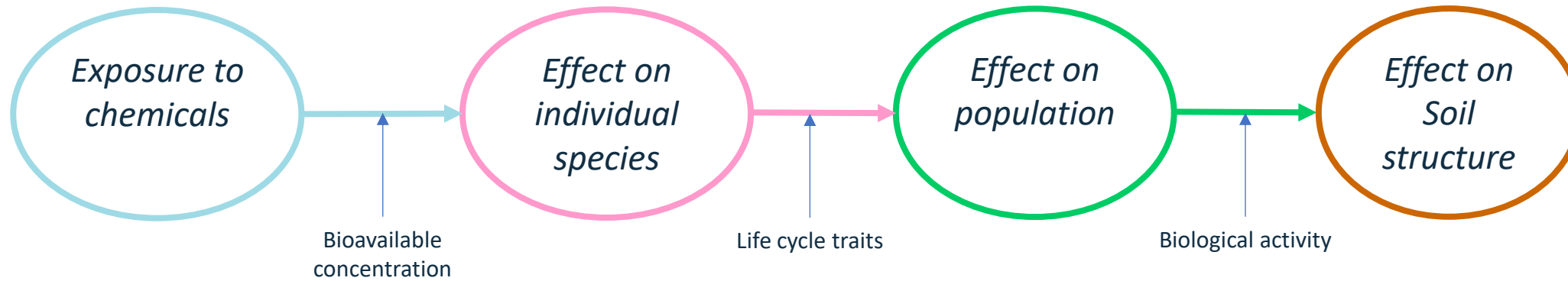
- track impact of various processes driven by biological actors on soil structure,
- express variation of soil structure as a function of the activity of biological actors,
- focus on relevant soil processes allowing for assessment of impact of pollution impact on soil functions.

Soil Porosity: (co)regulates 25 processes across 4 functions

Porosity (co)regulated processes	Functions		
Soil respiration	C		
Extracellular depolym.	C	N	B
Methanogenesis	C		
Aggregate formation	C	W	B
Aggregate stabilization	C		
Ammonia volatilization	C		
Denitrification	C		
Adsorption/desorption	N	W	
Precipitation dissolution	N	W	B
Microbial immobilization	N		
Ammonia volatilization	N		
Nitrification	N		
Biopolymer degradation	N		B
Infiltration	W		
Evaporation	W		
Capillary rise	W		
Subsurface lateral flow	W		
Drainage	W		
Physical occlusion	W		
Solute retention	W		
Reduction	W		
Volatilisation	W		
Plant interactions	B		
Pollutant degradation	B		
Water availability	B		



Biota exposure pathway



Building modelling scenario for calculating chemical concentration in soil compartments

Set of parameters to describe local conditions:

- Bare soil,
- Vegetation covered soil.

Soil

- Concentration of the pollutant in river water
- Cultural coefficient
- Direct application on topsoil per day and per surface unit
- Dry deposition flux of contaminated aerosols that is intercepted by vegetation
- Duration of the daylight during one day
- Duration of the sunshine during one day
- Irrigation rate of cultivated fields
- Irrigation rate of cultivated fields that is intercepted by vegetation
- Maximum radiation
- Measured Actual Evapotranspiration
- Rainfall per day and unit surface
- Surface dry deposition flux of contaminated aerosols
- Surface wet deposition flux of contaminated aerosols
- Temperature in air
- Temperature in soil
- Wet deposition flux of contaminated aerosols that is intercepted by vegetation

- Top -

Diffusion coefficient in water

- Diffusion coefficient of oxygen in water
- Diffusion coefficient of water in air
- Molar mass of dioxygen
- Molar mass of water
- Universal gas constant

Soil

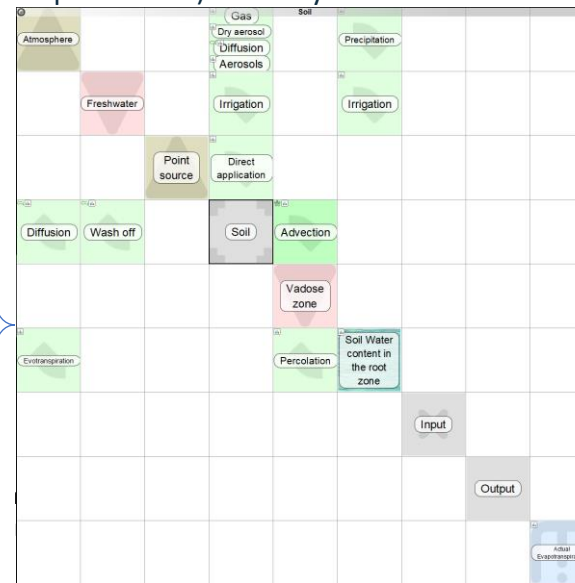
- Bioturbation diffusion coefficient
- Boundary layer thickness in atmosphere above the soil
- Degradation increase factor
- Depth of the root zone
- Diffusion coefficient of water vapour in air
- Dry density of soil
- Fraction of organic matter in soil
- Fraction of Soil Water depleted before moisture stress
- Initial concentration in deep soil
- Initial concentration in topsoil
- Number of layers in soil
- Soil surface
- Soil water content at field capacity in the root zone
- Soil water content at wilting point in the root zone
- Theta 0
- Time step used for the calculation
- Wash-off rate constant
- Water-Soil partition coefficient for metals

'Soil' model dynamically simulates the distribution of organic contaminants and metals in abiotic media (i.e. soil particles, pore water) of soil systems

Time series

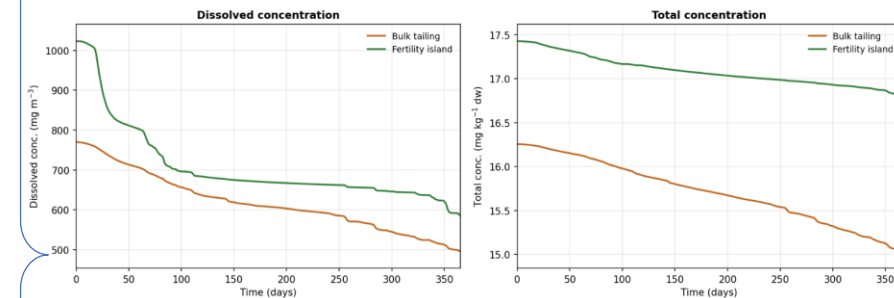
Chemical properties

Soil properties



Soil metal pollution in La Unión-Sierra de Cartagena located in Spain (SOILPROM 7th use case)

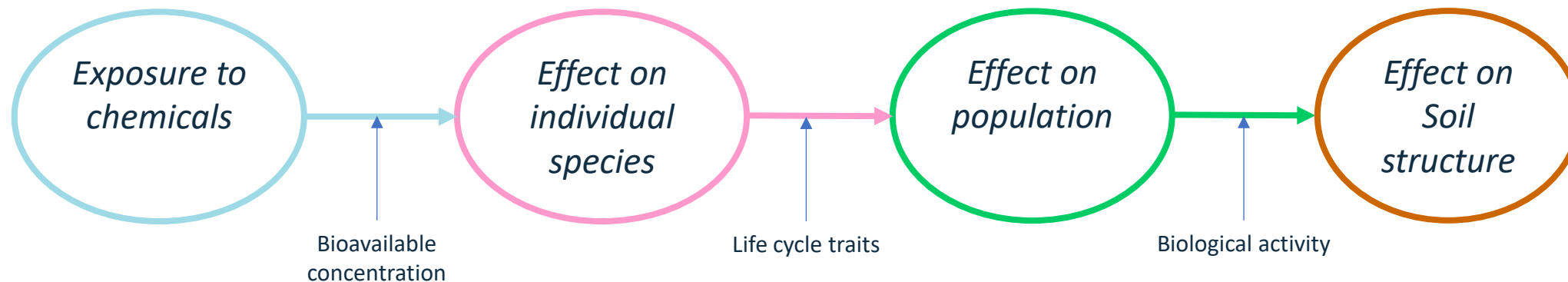
Cadmium — soil concentration: Bulk tailing vs Fertility island



Model output:

- Change in total and dissolved metal concentration in time,
- Top and deep soil compartments,
- Also process rates (advection, diffusion)

Biota and soil structure impact pathways



Modelling impact from individuals to population and coupling to soil porosity

Extrapolating life history endpoints of exposed individuals to population development.

Individuals' life traits affected by exposure to chemicals can be linked to population level processes e.g., rate of increase ($r(C)$) or carrying capacity ($K(C)$).

$$\frac{r(C)}{r(0)} = \frac{K(C)}{K(0)} = \text{reproduction reduction} * \text{survival reduction}$$

$r(C), r(0)$ intrinsic rates of increase of exposed and unexposed populations.
 $K(C), K(0)$ population carrying capacities of exposed and unexposed populations.

Earthworm and/or plant related variables such as **biomass**, **root production** and **ingestion rate** can be directly incorporated in the modelling of soil porosity

E.g., budget model for net change in soil macroporosity (Gibbs & Reid, 1988)

$$\Delta E_{100} = T + \tau_s + R_d - R_g - S$$

ΔE_{100} are macropores with $\phi > 100$

T tillage

τ_s soil turnover rate due to bioturbation, directly proportional to earthworm biomass and ingestion rate and $\frac{I_r \times E_{bio}}{\gamma_b}$, I_r - ingestion rate, E_{bio} - earthworm biomass, γ_b - bulk density

R_d/R_g root decay/growth

S shrinking due to soil drying

Hazard data - workflow – heavy metals



WoS
Literature
search

AB =
(contaminant name)
AND (toxic* OR ecotoxic*)
AND soil*
AND (
annelid* OR oligochaet* OR earthworm* OR enchytraeid*
OR mollusc* OR gastropod* OR nematod* OR tardigrad*
OR arachnid* OR spider* OR acar* OR mite* OR pseudoscorpion*
OR diplopod* OR milliped* OR chilopod* OR centiped*
OR isopod* OR hexapod* OR collembola* OR springtail*
OR insect OR insects
OR beetle* OR coleopter* OR diptera* OR ant OR ants
OR protura* OR diplura*
OR plant*
OR bacteri* OR fung* OR mycorrhi* OR endomycorrhi*
OR endo-mycorrhi* OR ectomycorrhi* OR ecto-mycorrhi*
OR microb* OR microorganism*
)

As - Cd - Pb - Zn

+ now we test AI automation

	Soil invertebrates		Microorganisms	
	Relevant studies	Endpoints	Relevant studies	Endpoints
As	10	70	6	33
Cd	47	649		
Pb	34	194	30	98
Zn	51	500	43	127



This project has received funding from the European research and innovation programme under grant agi

TOGETHER, LET'S COMBAT SOIL POLLUTION!

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