



Martin H. Gerzabek

**President of the Christian Doppler
Research Association**

Panel 1

Healthy Soil

What Makes Soil Resilient?

Univ.-Prof. DI Dr. Dr. h.c. mult. Martin H. Gerzabek

Institute of Soil Research

Department of Ecosystem Management, Climate and Biodiversity

BOKU University

Contents of the keynote

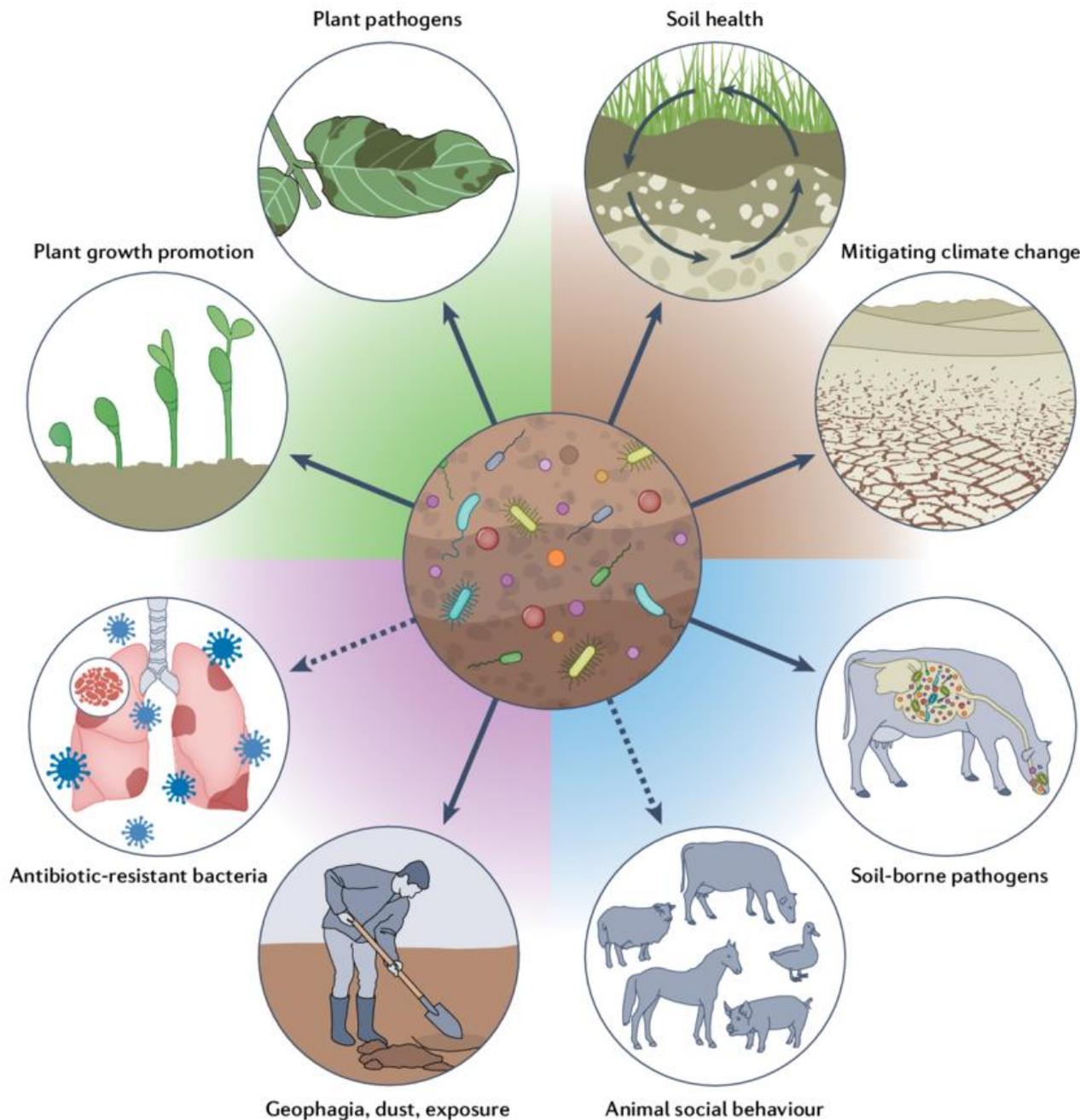
- Introduction: Soils in the One Health concept
- Soil functions / ecosystem functions
- Threats to soil resources
- Possible criteria/measures for keeping soils „healthy“ and „resilient“

Role of soils in the „One health“ concept



The concept of “One Health” highlights that human health is not isolated but connected to the health of animals, plants and environments.

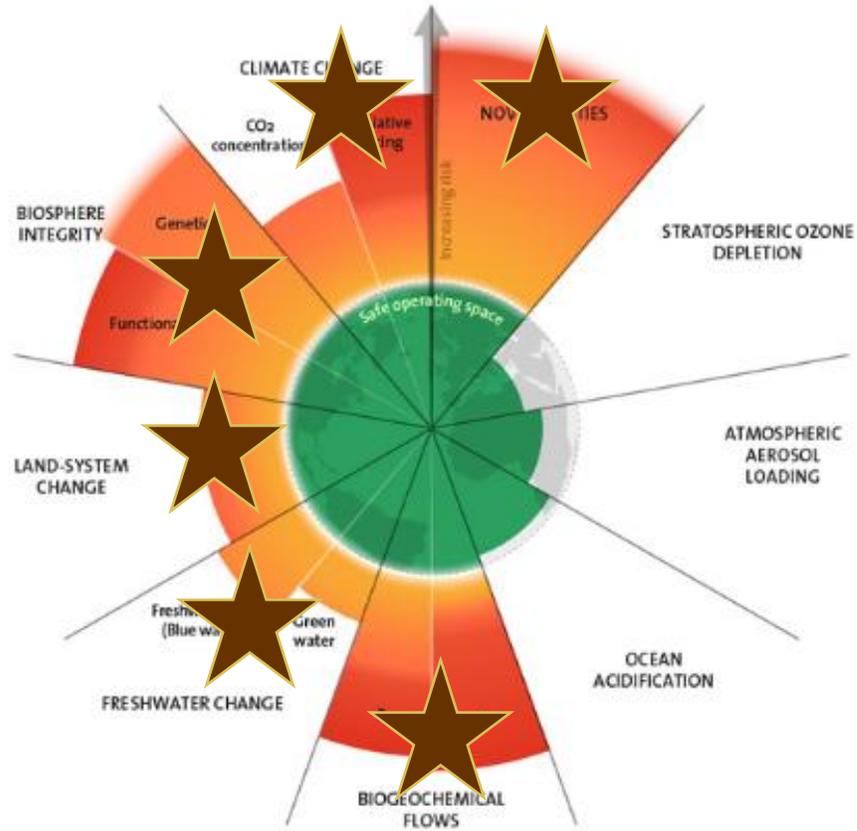
S. Banerjee & M. G.A Van der Heijden, 2022 Nature Reviews
Microbiology 21(1):1-15



S. Banerjee & M.G.A Van der Heijden, 2022:

Direct and indirect effects of the soil-microbiome on environmental compartments, humans and animals.

2023



9 boundaries assessed,
6 crossed

Soils play a central role in biogeochemical cycles, biodiversity and ecosystem functioning

Planetary boundaries

J. Lokrantz/Azote
based on Steffen et al.
2015; 2023

BII: Biodiversity Integrity Index

E/MSY: Extinctions per Million species and year

Novel entities: microplastic, nanomaterials, radioactivity,

....

The most important soil functions

Food sovereignty

Biodiversity



Production and biomass Biological heritage and reserve gene Filtering/buffering

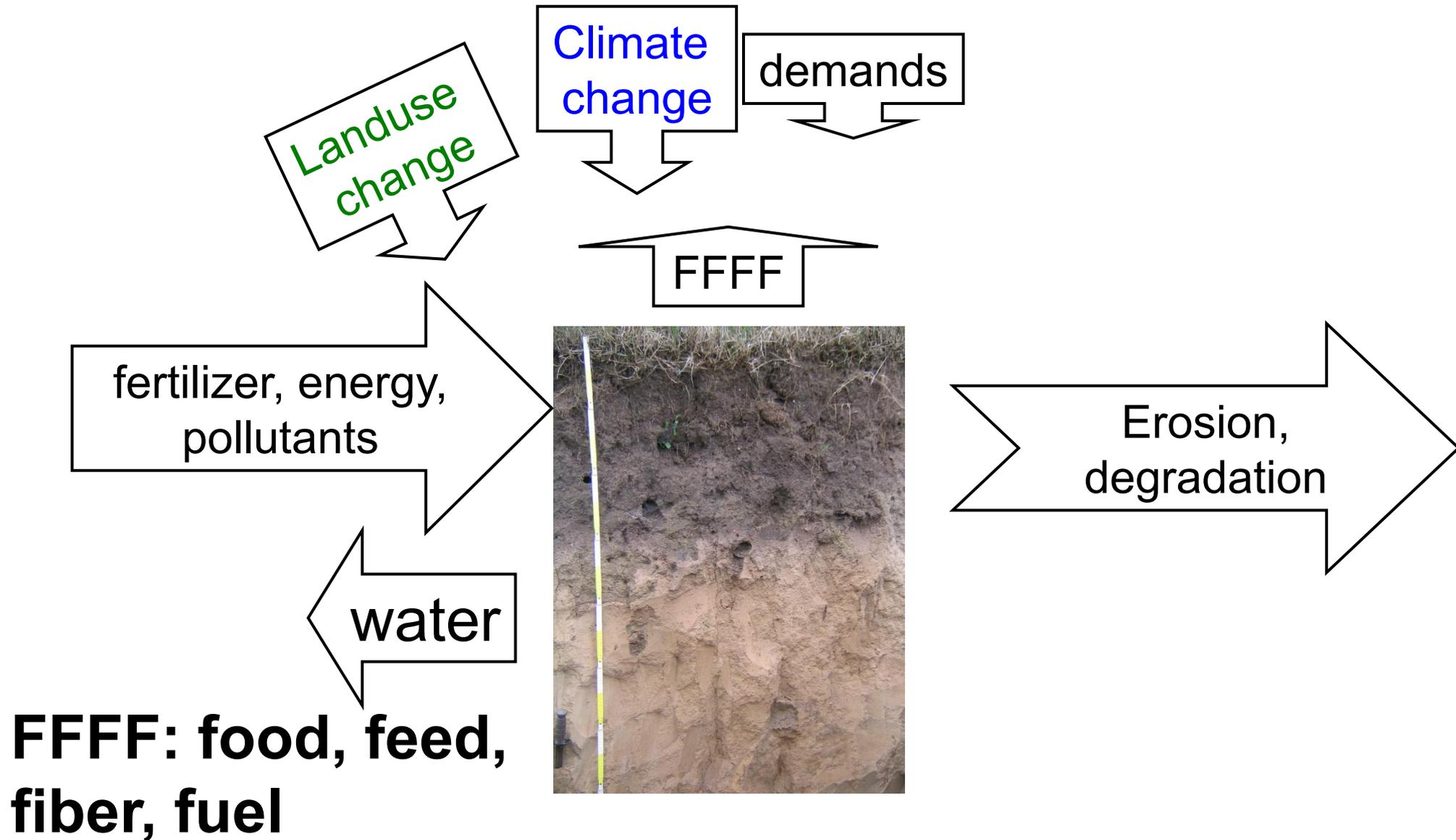
Water, nutrient, contaminant cycles/regulation



Source of raw materials Geogenetic and cultural heritage Physical and spatial base

Negative effects

Challenges of present and future soil use



Soil health

Soil health is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.

=

Maintain soil functions

Site
specificity
of soil
functions
/soil
health!



Enormous diversity
of soils and their
functions!

- a) Slowenien,
- b) Polynesien,
- c) Thailand,
- d) Kanada,
- e) Sudan,
- f) Österreich,
- g) Mexiko

Photos: M.H. Gerzabek 1984-2006

Some soils of the Galápagos Islands (chronosequence, 1,070 ka) developed on scoria (Zehetner, Gerzabek, et al. 2019 – 2025)



CH 1,
Entisol/Regosol,
Isabela, age: $\sim 1.45 \pm 0.03$ ka



CH 2,
Andisol/Andosol,
Isabela, age: $\sim 4.3 \pm 0.06$ ka



CH 3,
Inceptisol/
Cambisol,
Florea, age:
 $\sim 26 \pm 7$ ka



CH 4,
Alfisol/Lixisol,
Santa Cruz, age: $\sim 165.5 \pm 11.6$ ka



CH 5,
Ultisol/Acrisol,
San Cristobal,
age: $\sim 825.6 \pm 11.2$ ka



CH 5a,
Vertisol, San
Cristobal,
age: $\sim 812.9 \pm 9.6$ ka; very
dry



CH 6,
Oxisol/Ferralsol,
San Cristobal,
age: $\sim 1070 \pm 10$ ka

Soil functions change dramatically with soil development – and with management!

Threats to soil functions and soil health

- Quantitative:
 - Sealing
 - Erosion
 - Landslides
- Qualitative
 - Agric. and forestry overexploitation
 - Compaction
 - Contamination
 - Biodiversity loss

Threats to soil functions

- Quantitative:

- **Sealing**

- Erosion
 - Landslides

- Qualitative

- Agric. and forestry overexploitation
 - Compaction
 - Contamination
 - Biodiversity loss

Austria:

Loss of agricultural land (conversion to land for construction): approx. 6.5 hectares per day (mostly in prime locations, sealing approx. 50%)

Europe:

Loss of agricultural land approx. 1500 km² per year, or 430 ha per day

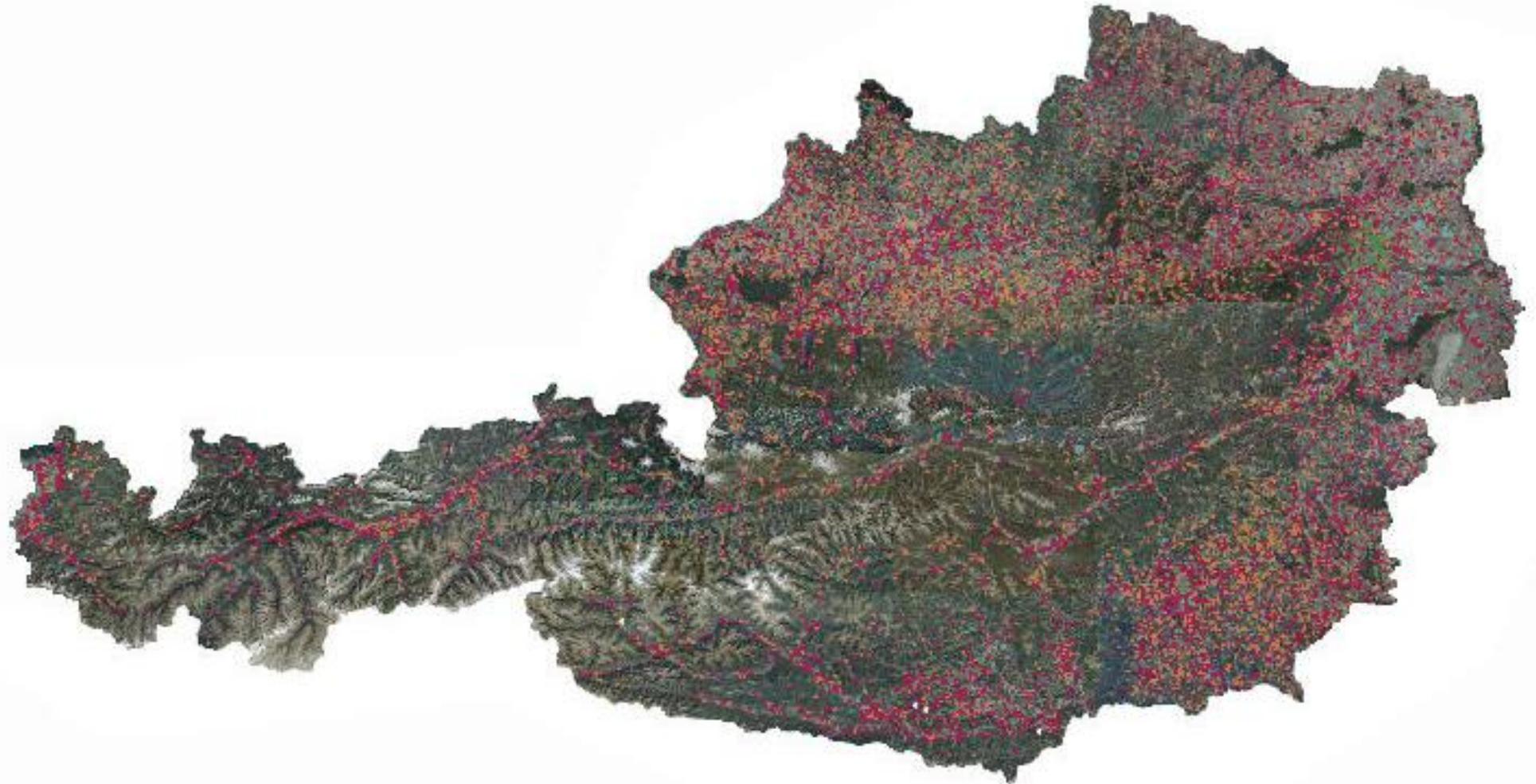
Land use for infrastructure in Austria in 2026

Umweltbundesamt, 2026

Hauptklassen

OGD_FI

-  Verkehr
-  Siedlung innerhalb
Baulandwidmung
-  Siedlung außerhalb
Baulandwidmung
-  Freizeit- und Erholung
-  Ver, Entsorgungs- und
Abbaufächen
-  Freiflächen PV- und
Windkraftanlagen
-  others



Threats to soil functions

- Quantitative:
 - Sealing
 - **Erosion**
 - Landslides
- Qualitative
 - Agric. and forestry overexploitation
 - Compaction
 - Contamination
 - Biodiversity loss
- Soil material displacement by water and wind
- Natural process, intensified by humans
- Loss of fertile (fine-grained) soil material (clay and humus fractions)
- Total area worldwide: wind erosion: 55.9 million km², water erosion: 32.4 million km²
- Europe: approx. 17% of land area affected by erosion
- Annual losses in Europe: 5–27 tons/ha/year depending on the country
- Erosion is a factor 10 to 1000 times greater than soil formation

8.4 Gefährdungen

Flächenhafter Bodenabtrag durch Wasser
Areal soil loss by water

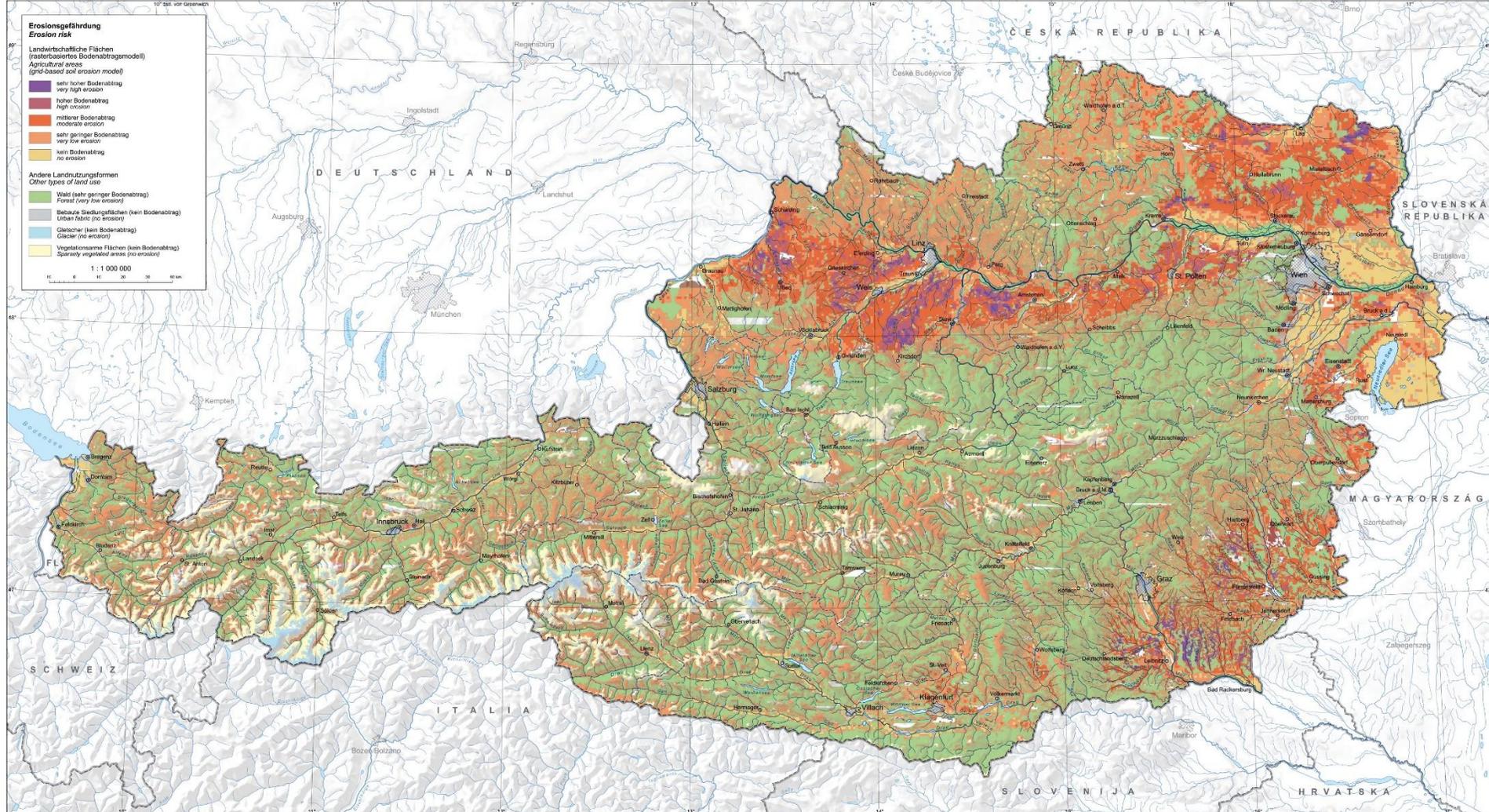
Wissenschaftliche Bearbeitung:
Scientific evaluation:
2005

Datengrundlagen:
Data basis:
Niederschlag / Precipitation 1961 - 1990
CORINE Bodenbedeckung / Landcover 2000
Agrarstrukturerhebung / Agr. structure survey 2001
Öster. Bodenkartierung / Agr. soil mapping

Thematische Bearbeitung:
Thematic elaboration:
P. Strauss, BAW Pezzenkirchen

Kartografische Bearbeitung:
Cartographic elaboration:
R. Hemdl, J. Fürst, IHW-BOKU Wien
K. Kriz, IGR Univ. Wien

Herausgeber/Published by:
Bundesministerium für Land- und Forstwirtschaft,
Umwelt und Wasserwirtschaft, Wien
© 2007 Universität für Bodenkultur Wien
Vertrieb/Distribution:
Österreichischer Kunst- und Kulturverlag Wien

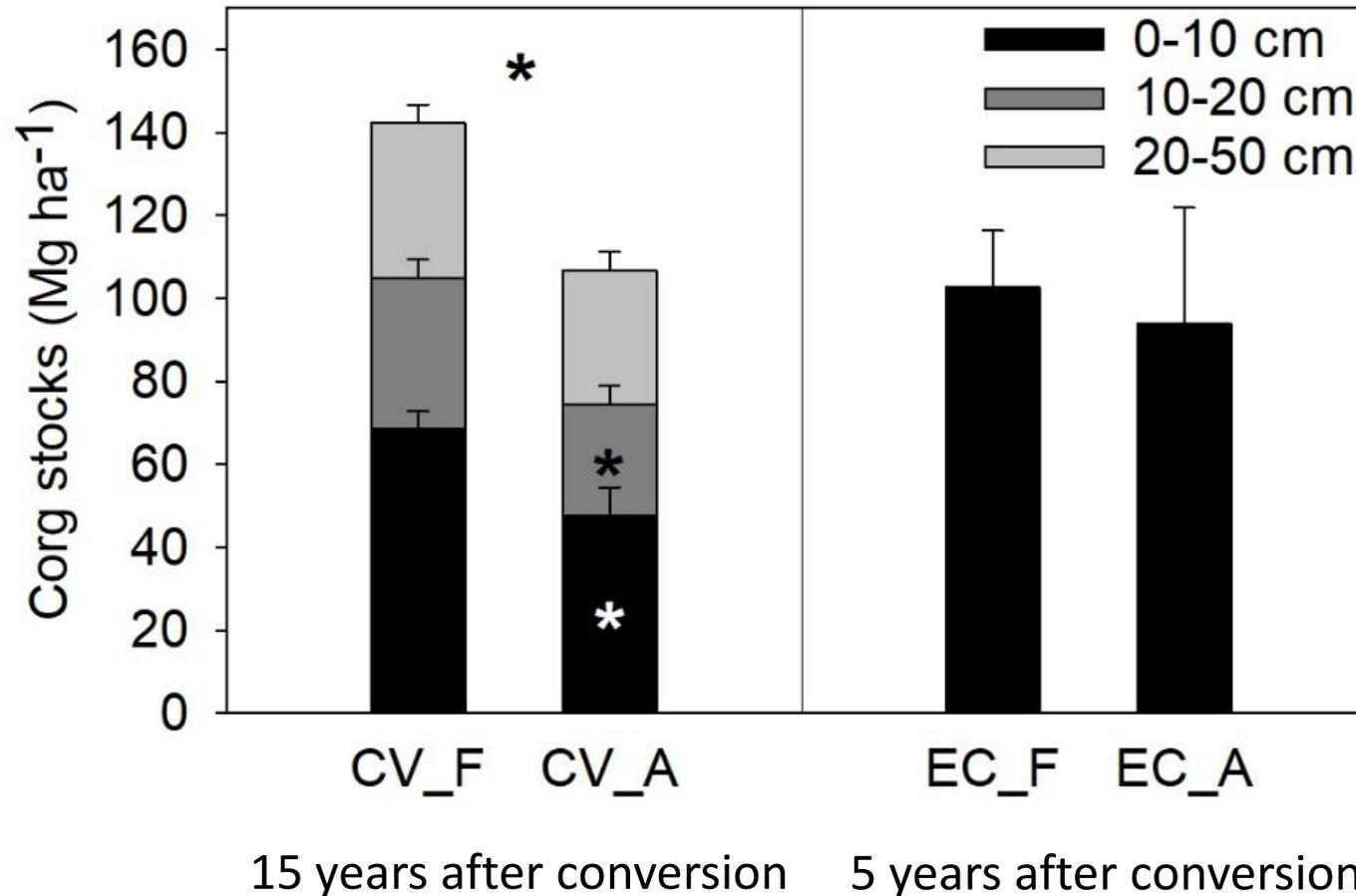


Strauss P. (2007): **Extensive soil erosion hazard caused by water**. In BMLFUW (ed.) Hydrologischer Atlas Österreichs. 3. Lieferung. Kartentafel 8.4. Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. ISBN 3-85437-350-7.

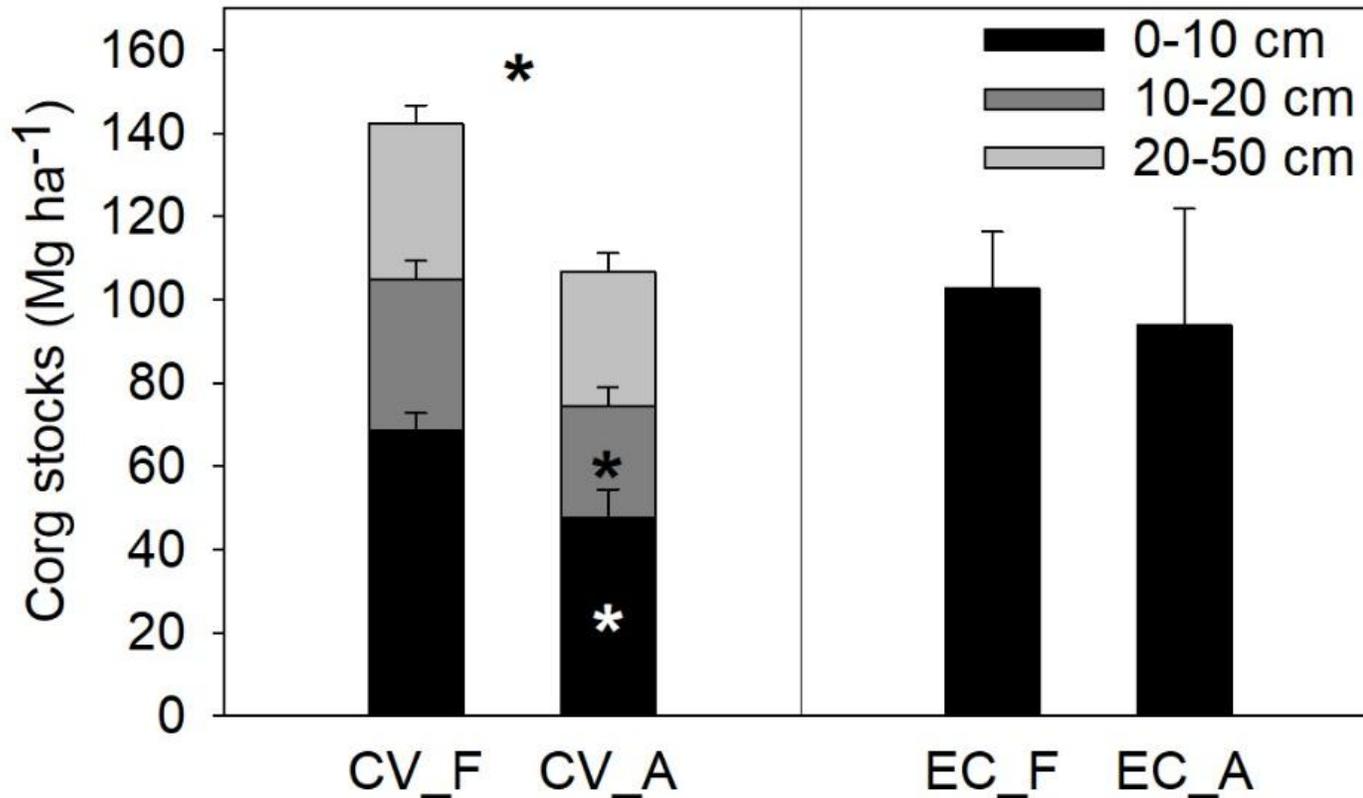
Threats to soil functions

- Quantitative:
 - Sealing
 - Erosion
 - Landslides
 - Qualitative
 - **Agric. and forestry overexploitation**
 - Compaction
 - Contamination
 - Biodiversity loss
 - Frequent operation with (heavy) machinery
 - Excessive application of fertilizers and pesticides
 - Monocultures
 - Unsustainable forest harvesting techniques
- lead to**
- Humus and biodiversity loss
 - Compaction
 - Poor soil structure – erosion
 - Changes in pH values
 - Contamination

C_{org} stocks; comparison arable vs. forest land-use in Cerro Verde and El Cascajo (Galápagos, Gerzabek et al., 2019)



C_{org} stocks; comparison arable vs. forest land-use in Cerro Verde, and El Cascajo



- At CV: 25% C_{org} loss in 15 years, ~ 1.66% per year
- N_t losses closely correlated with C_{org} losses



Threats to soil functions

- Quantitative:
 - Sealing
 - Erosion
 - Landslides
- Qualitative
 - Agric. and forestry overexploitation
 - **Compaction**
 - Contamination
 - Biodiversity loss

Compaction is the „**hidden**“ soil threat, it is invisible on the first glance.

Causes: Use of excessive heavy machinery, frequent traffic on the soil, failure to observe moisture content - cultivation when soil is too wet;

Humus decrease

Result:

- Increased nitrate leaching,
- Accelerated erosion,
- Roots can penetrate the soil only with difficulty
- Reduced biological activity

Not easy to mitigate!

Threats to soil functions

- Quantitative:

- Sealing
- Erosion
- Landslides

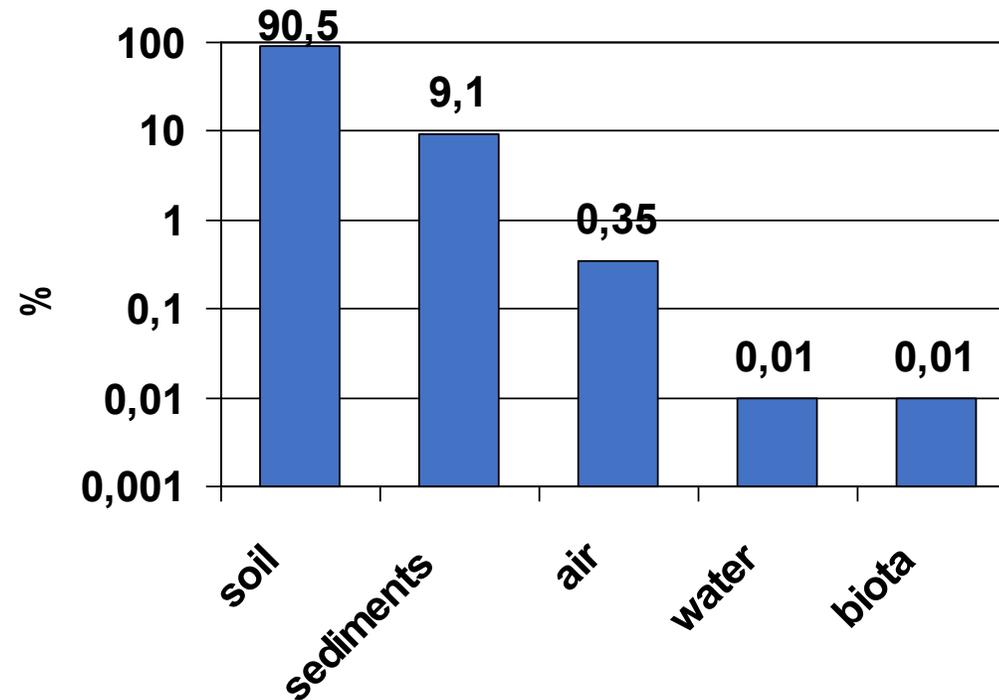
- Qualitative

- Agric. and forestry overexploitation
- Compaction
- **Contamination**
- Biodiversity loss

There are approximately 100,000 (EEA, 2003*: 30,000) **different chemical substances on the European market**; the **whereabouts** of a large proportion of these is **unknown**.

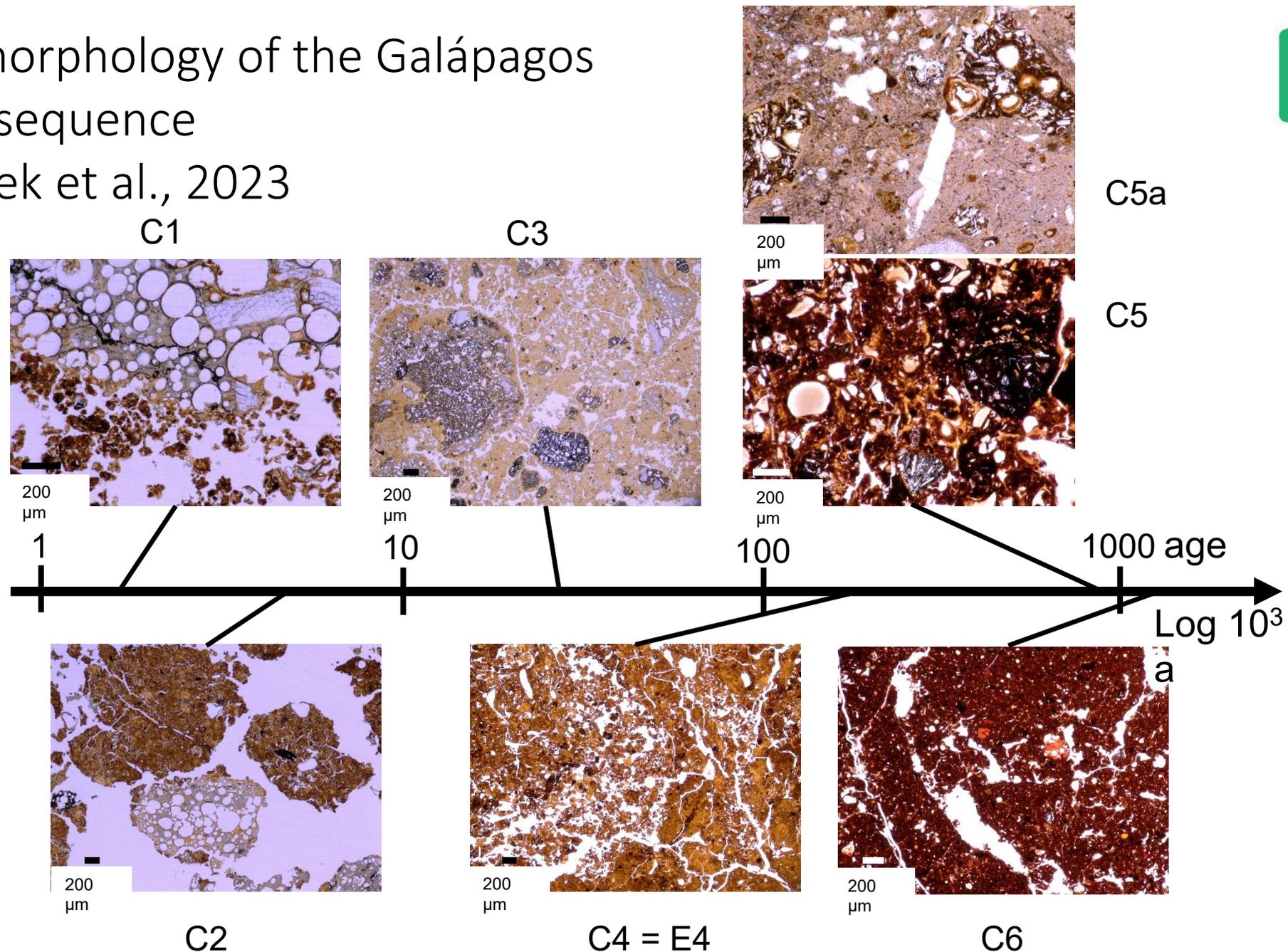
In many cases **soil is the final sink** (not only for agrochemicals); due to its large inner surface and reactive interfaces it adsorbs many contaminants and **partly detoxifies organic compounds**.

Distribution of persistent organic pollutants in environmental compartments (equilibrium situation), (modified, according to Crosby 1982)



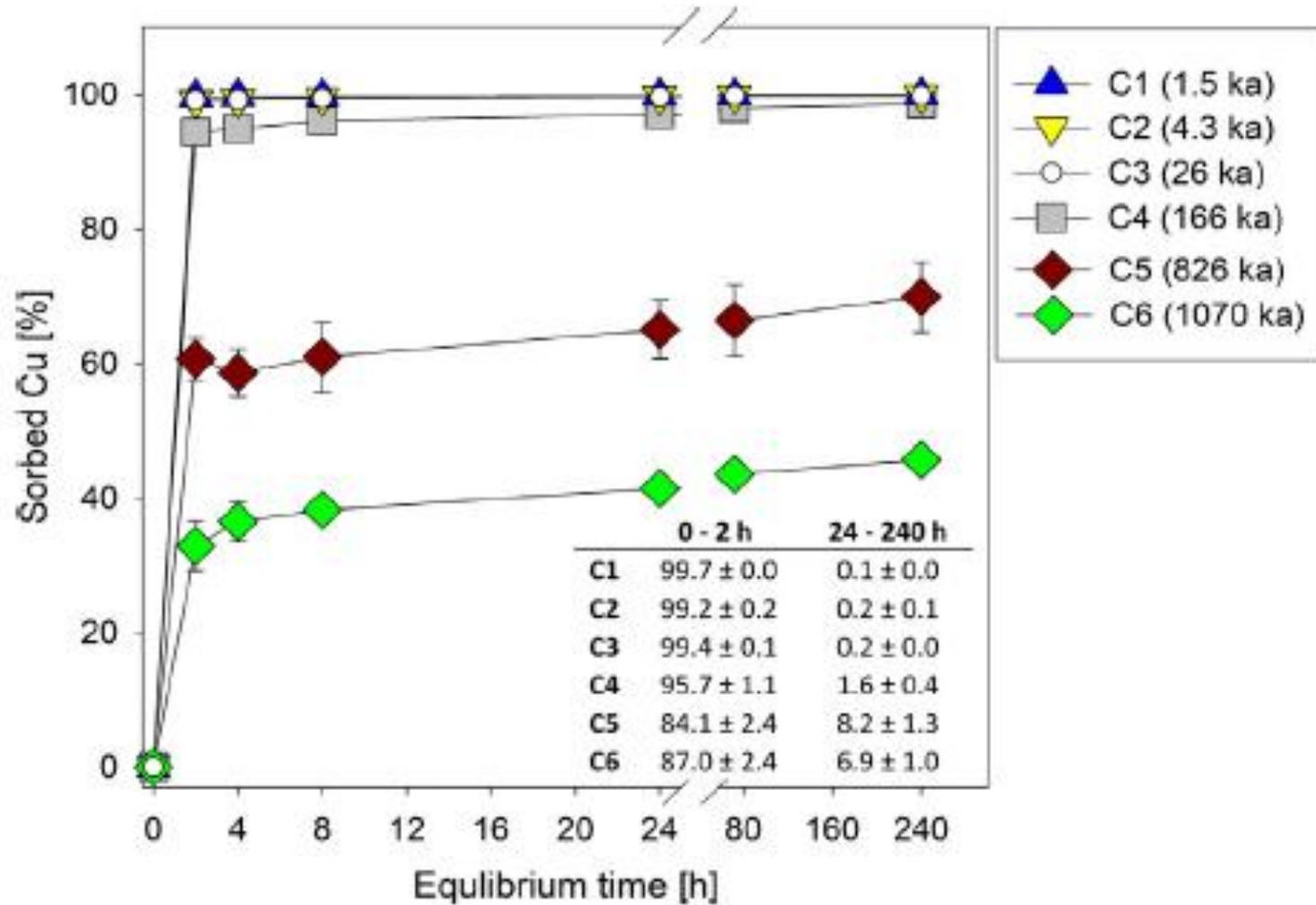
Micromorphology of the Galápagos chronosequence

Gerzabek et al., 2023



Cu-Adsorption isotherms in soils of different age on the Galápagos Islands.

RECHBERGER, M.V., ZEHETNER, F., CANDRA, I.N., GERZABEK, M.H., (CATENA, 2020)



Threats to soil functions

- Quantitative:
 - Sealing
 - Erosion
 - Landslides
- Qualitative
 - Agric. and forestry overexploitation
 - Compaction
 - Contamination
 - **Biodiversity loss**

Caused by:

- Monocultures and poor crop rotation
- Contamination (including agricultural chemicals)
- Compaction
- Lack of soil-conserving cultivation methods

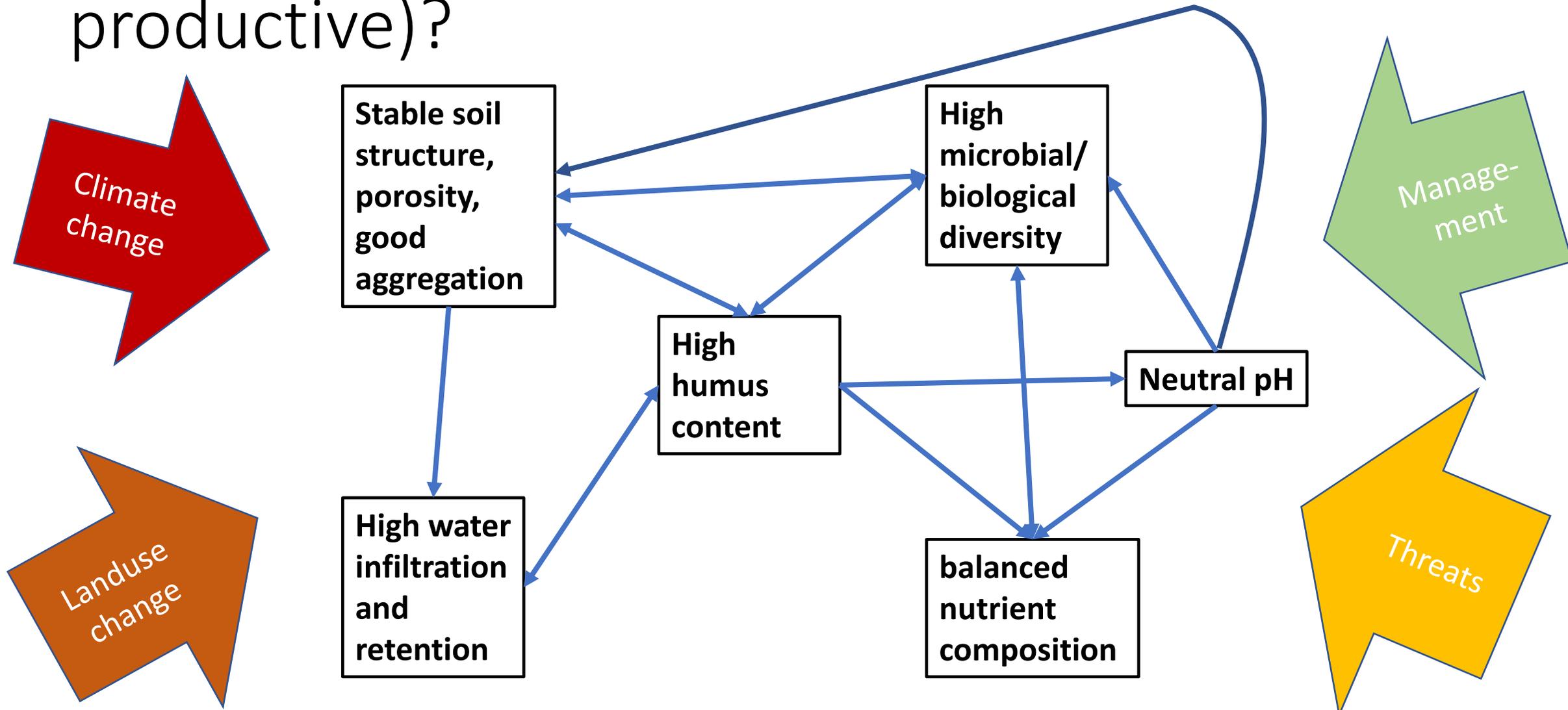
Leads to reduced soil functions (less detoxification, hampered biogeochemical cycles (incl. C, N, P,...), slower release of plant nutrients....)

Resilience

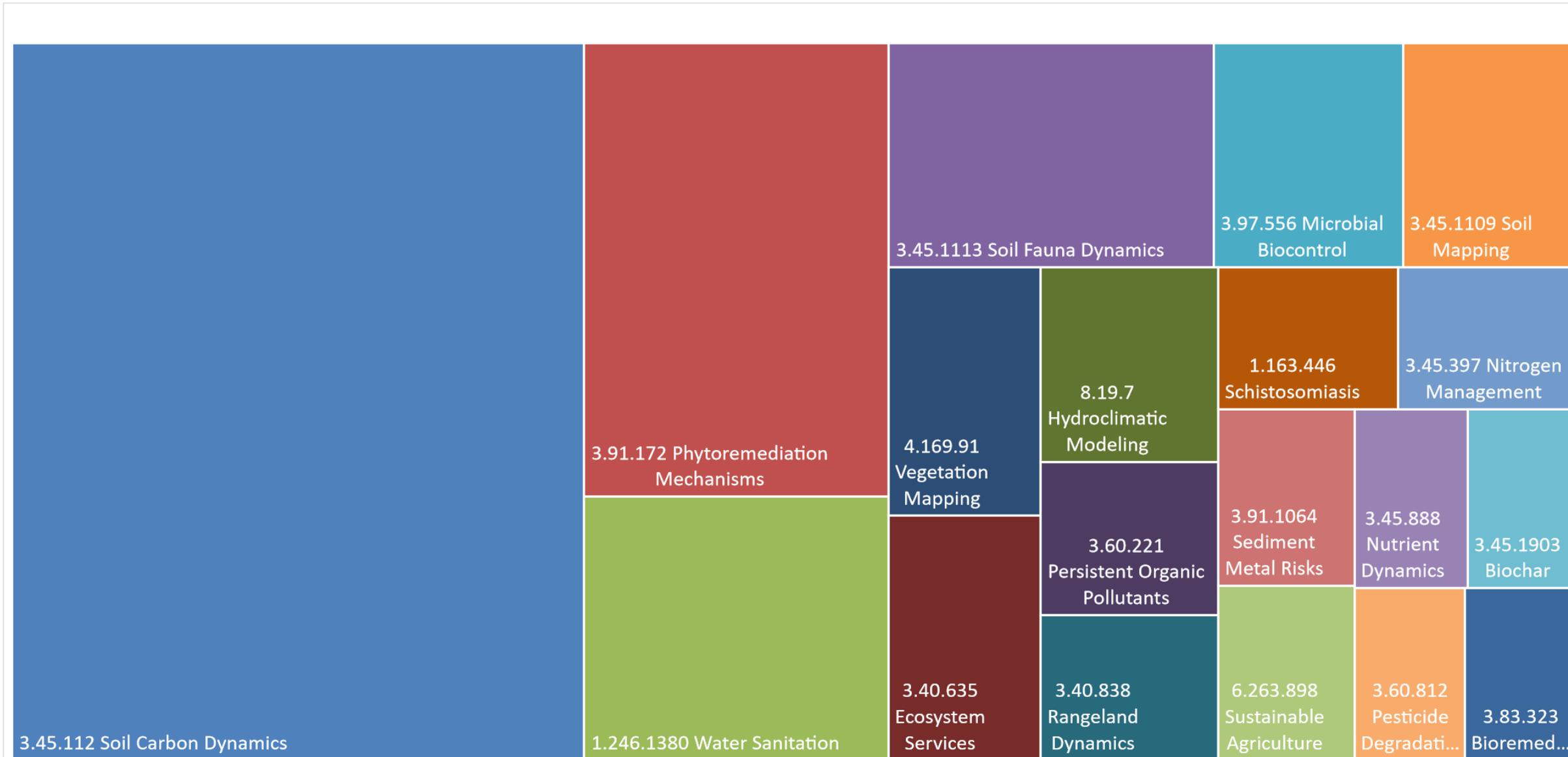
- Definition:
 - i) the capacity to withstand or to recover quickly from difficulties; toughness.
 - ii) the ability of a substance or object to spring back into shape; elasticity.

Soil resilience refers to the ability of a soil to resist or recover its healthy state in response to destabilizing influences.

What makes a soil resilient (and productive)?



Literature search Web of Science, August 12th, 2025: Soil&Health&Indicator



Soil health – improving resilience

ideas for criteria (based on AgriLife, ELO)

- **Land and Soil**

- Minimise negative land use change (sealing!)
- Promote healthy soils
 - % of minimum tilled cultivated land p.a.
 - # of passes per crop (tillage intensity) p.a.
 - Conservation of cereal stubble during intercrops
 - % of the soil covered p.a.
 - % land under temporary grassland p.a
 - # crops per crop rotation



Fotos: M.H. Gerzabek

Soil health – improving resilience

ideas for criteria

- **Land and Soil (continued)**

- Promote healthy soils

- # species in the crop rotation (incl. cover crops and/or intercrops)
- # use of soil health indicators (OM, SOC/Clay, Humus balance, Worm count, ...)
- Types of nutrients used
- # nutrient loss (nitrate) p.a.



Foto: M.H. Gerzabek

Soil health – improving resilience

ideas for criteria

- **Nature**

- Number of ha receiving Areas with Natural Constraints (ANC)
- Number of ha receiving support under Natura 2000 or the Water Framework Directive
- Number of ha (agricultural) covered by environment/climate commitments going beyond mandatory requirements
- Share of crop protection products in farm turnover
- Weed control management
- % natural habitat in agricultural land: # running meters hedge & bushes p.a., # isolated trees p.a., # running meters herbaceous and floristic cover (incl. wintering) p.a., # permanent meadows p.a., # extensive arable field margins p.a., # bird Islands p.a., # wild bees or insect nesting aid/preservation p.a., # rocks, gravel areas

Soil health – improving resilience

ideas for criteria

- **Nature (continued)**

- the distribution of the structural elements
- the management of the natural habitats
- the use of specific agricultural practices in grass and arable land
- Connectivity between semi natural habitat areas in agricultural land
- Average plots size

Foto: M.H. Gerzabek
Peat bog in Scotland



Conclusions

- Soil is a very complex system with manifold bearings on environmental processes.
- Soil health should be discussed in the framework of the „One Health“ approach
- Soil health includes all aspects of soil and related ecosystem functions
- A key element in maintaining or improving soil health and soil resilience is sustainable soil use and management. Regenerative agriculture
- Soil organic matter and its preservation and development are important keys to soil health and soil resilience.



Foto: M.H. Gerzabek

Thank you for your attention!