Linking spatial patterns of anecic earthworm populations, preferential flow pathways and agrochemical transport in rural catchments: an ecohydrological model approach

B I O P O R E

DFG-Project 2007-2011

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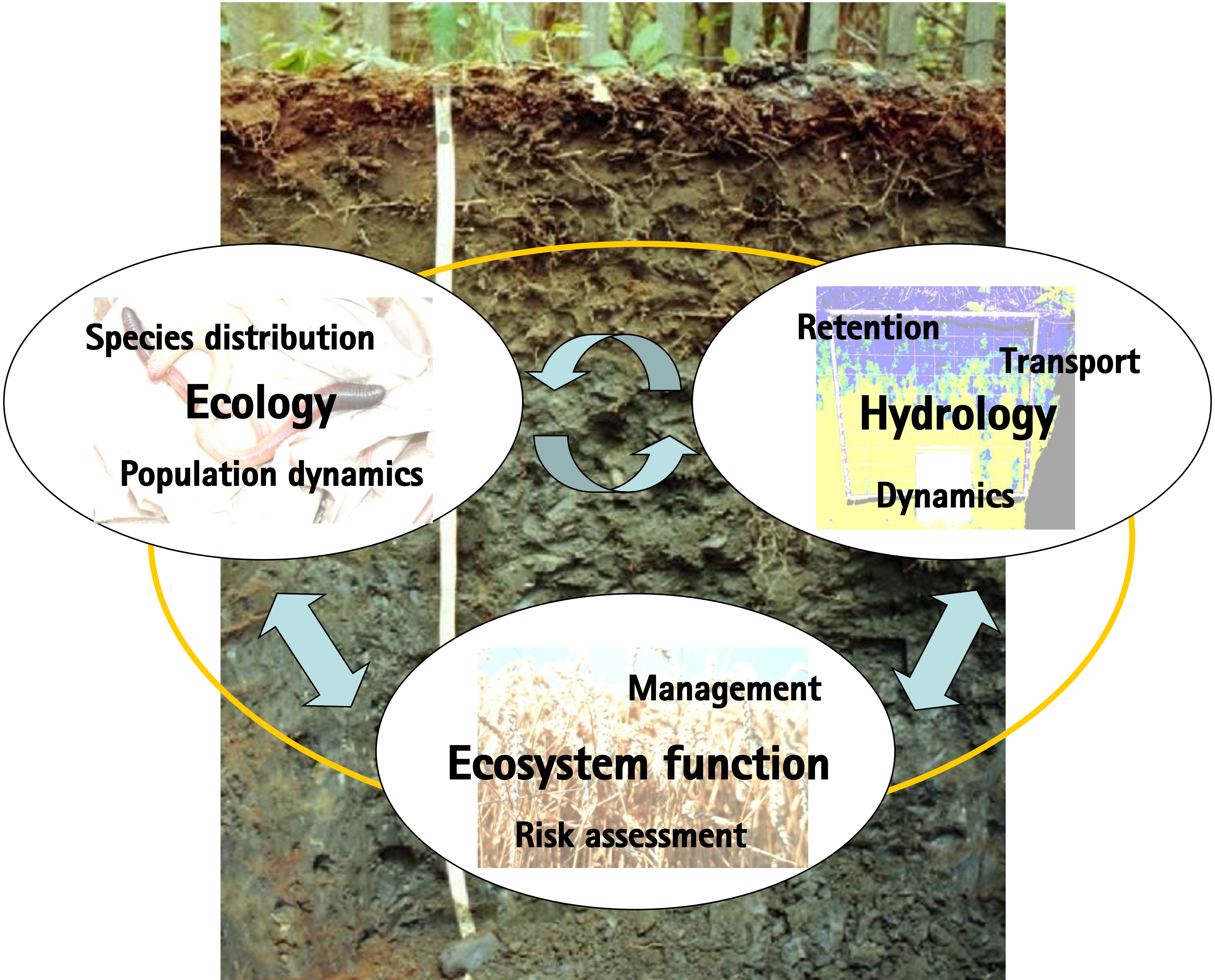
BIOPORE

Biopore



Aims

Integrated ecohydrological model linking

- Spatiotemporal distribution patterns and population dynamics of anecic earthworms
- Spatiotemporal patterns of connective preferential flowpaths (i.e. earthworm burrows)
- Spatiotemporal patterns of transport and degradation of agrochemicals considering feedbacks between abiotic and biotic processes

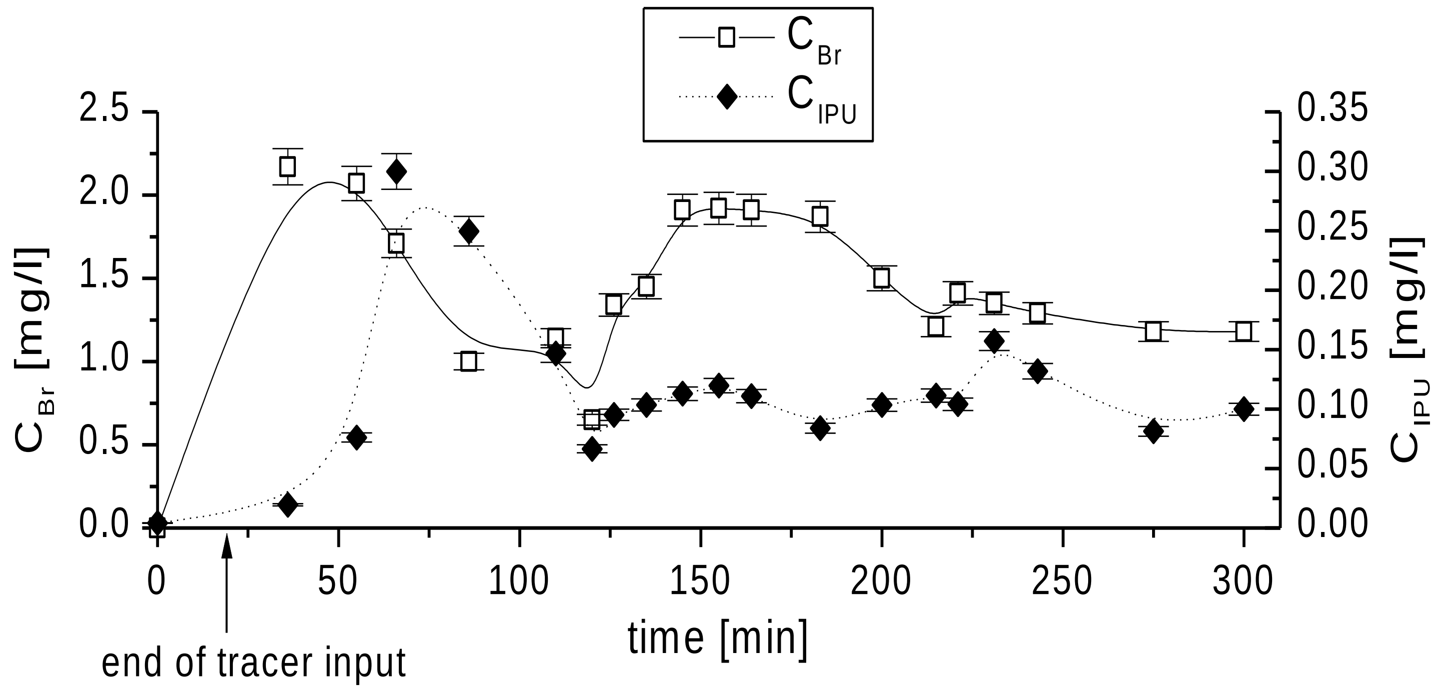
Preferential transport in agroecosystems

Weiherbach catchment: tile-drained arable land (1000 m²)

- Isoproturon application
- in three phases, tracer pulse after 10 min

Fast breakthrough in 1.2 m depth

- Tracer: 20 min, IPU peak: 50 min



Zehe E, Flühler H, 2001. Preferential transport of isoproturon at a plot scale and a field scale tile-drained site. J Hydrol 247: 100-115.

Preferential transport

Tracer experiments

- Earthworm burrows as transport pathways
- Fast transport: up to 340 µg/kg into 1 m depth within 2 h

additional experiments in 2008/09

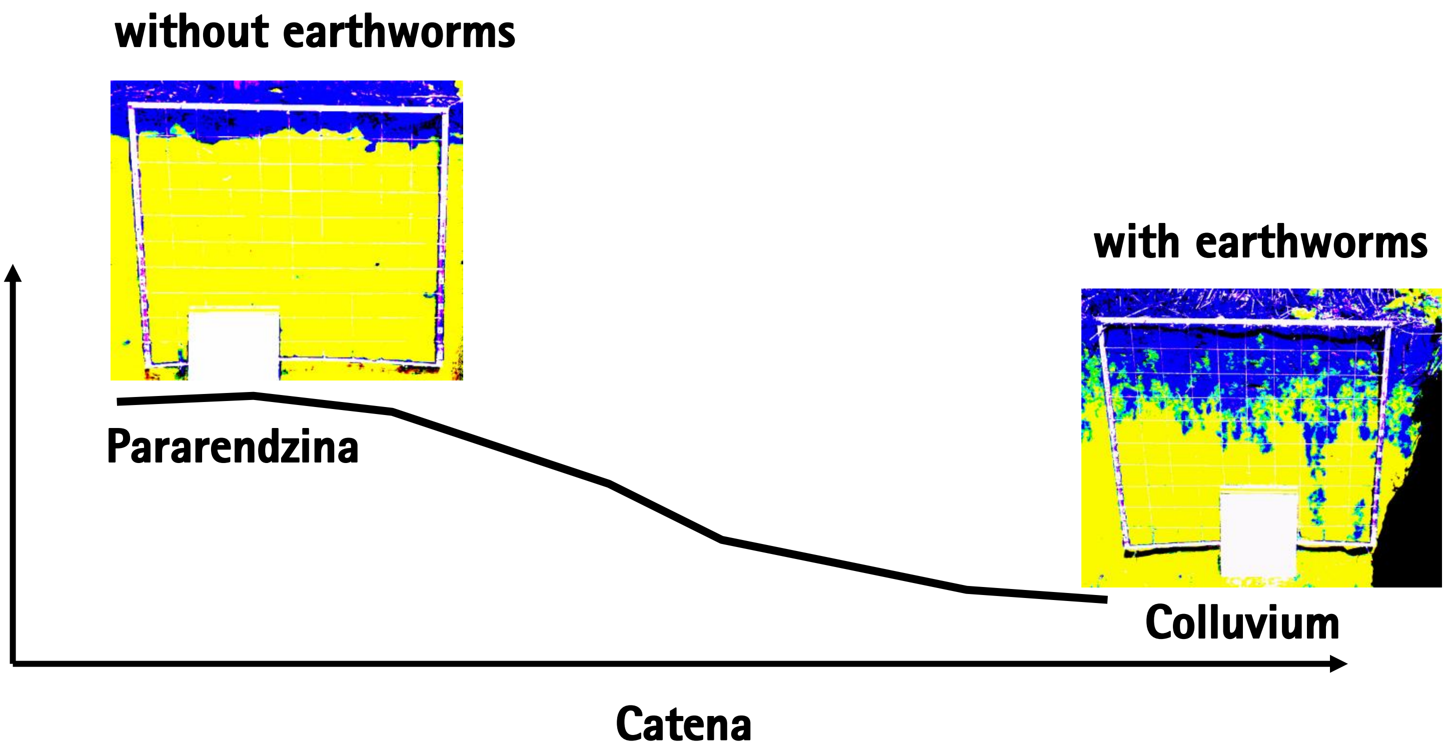
Zehe E, Flühler H, 2001. Slope scale distribution of flow patterns in soil profiles. J Hydrol 247: 116-132.

MOTIVATION

Spatial patterns on hillslope scale

Habitat preferences and erosion catena

- spatial organisation of transport patterns
- patterns of biogenic structures control transport
- essential for mobility of pesticides



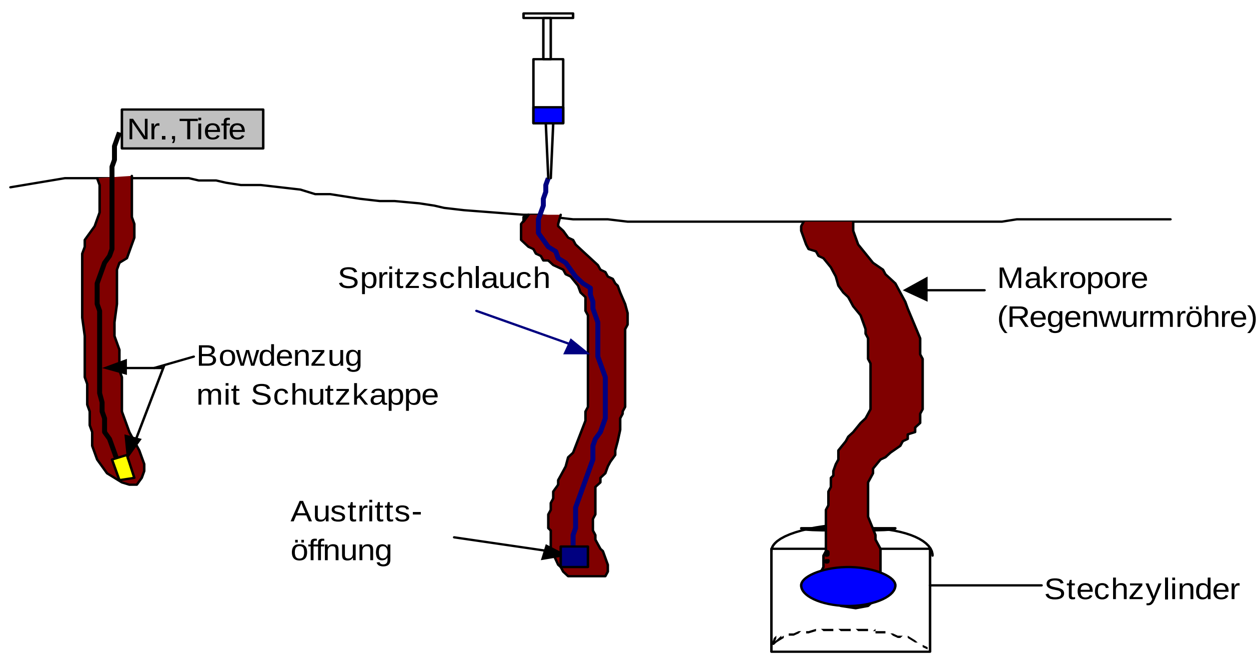
Zehe E, Flühler H, 2001. Slope scale distribution of flow patterns in soil profiles. J Hydrol 247: 116-132.

MOTIVATION

Transport and Environmental fate of pesticides

Experiments to investigate microbial IPU-degradation

- Top soil : 8-30 d
- Deeper soil layers (0,80 – 1m) : depending on location
- Earthworm burrows : 15 d (first order decay, co-metabolic)
- Soil matrix : > 150 d



Bolduan R, Zehe E, 2006. Mikrobieller Abbau des Heribizids Isoproturon in Bioporen & der Bodenmatrix .... J Plant Nutr Soil Sci 169: 87-94.

First synthetic modelling approach

1) Generation of realistic heterogeneous media

Soil matrix: turning bands
(mean ks= 10-6 m/s, Variance log(ks)=1, range 3m/50 cm,
Zehe et al., HESS 2006)

Macropores

- Density : Poisson-distributed (data: Zehe & Blöschl 2004)
- Length : Gaussian
- Burrowing activity : random walk
- Infiltration capacity : measurements

2) Simulation with CATFLOW

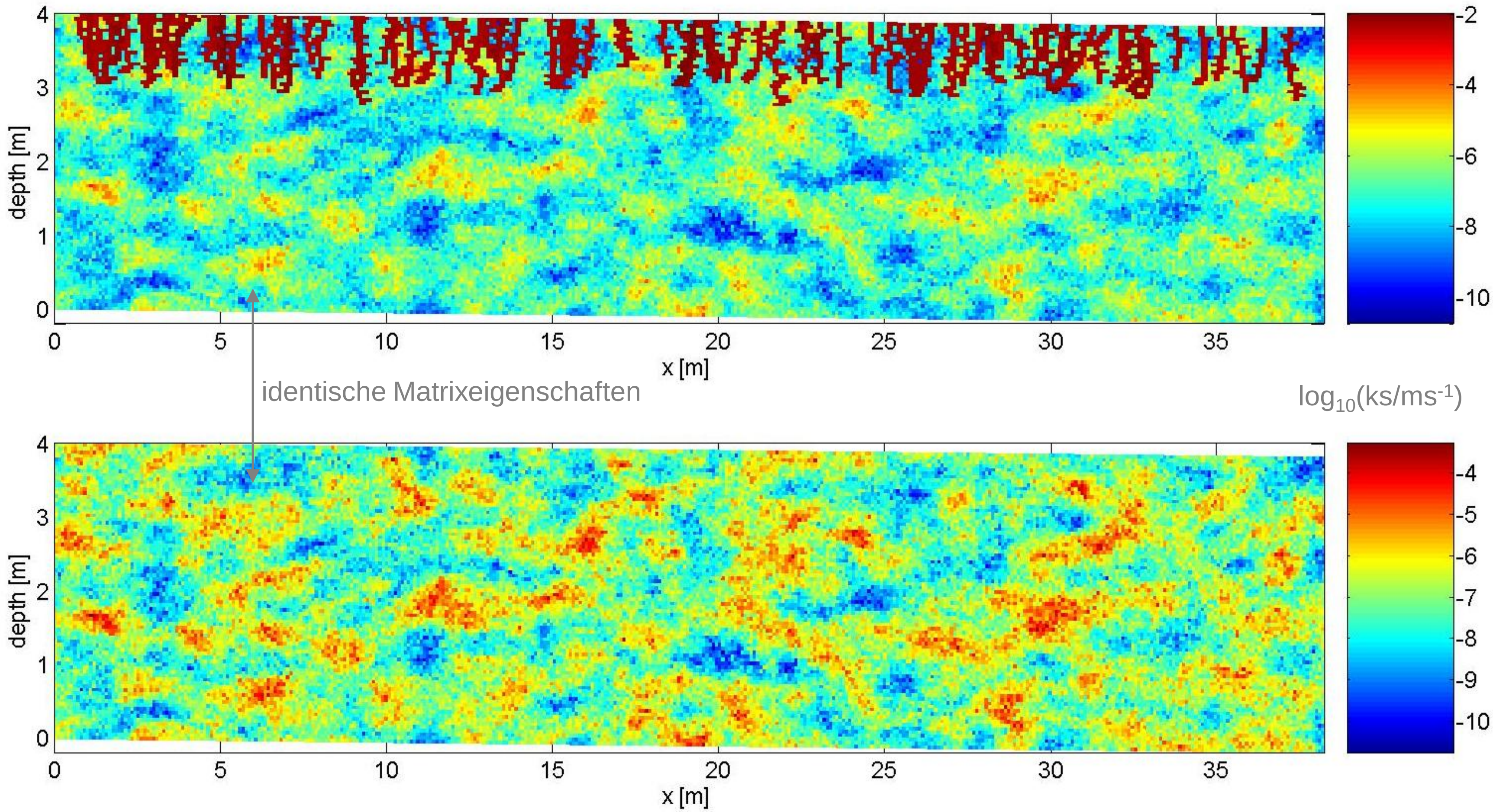
Erwin Zehe

Zehe E, Blöschl G, 2004. Predictability of hydrologic response at the plot and catchment scales .... Water Resour Res 40: W10202.

First synthetic modelling approach

1) Generation of realistic heterogeneous media

Matrix properties are identical on both cases

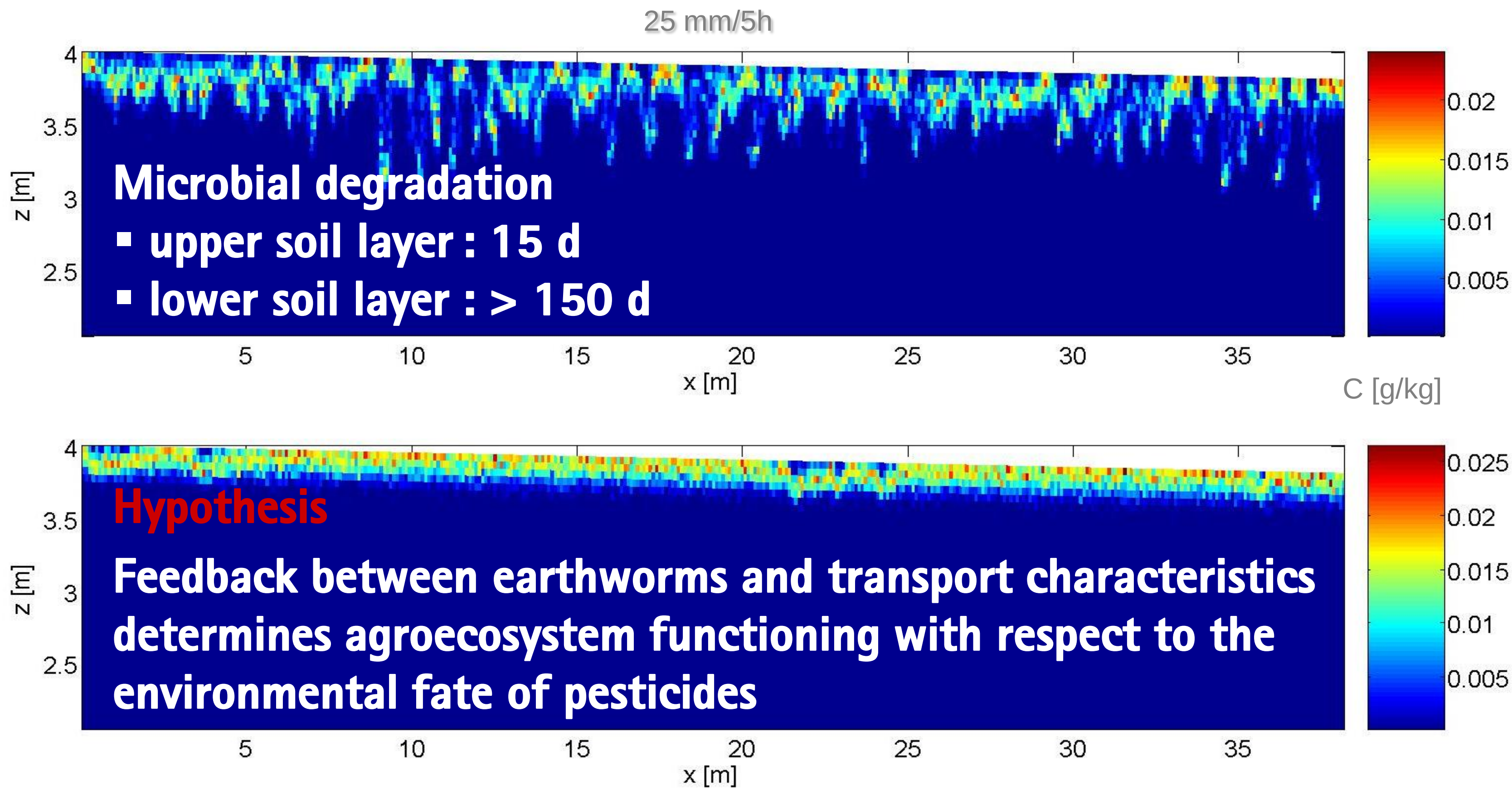


Erwin Zehe

Zehe E, Blöschl G, 2004. Predictability of hydrologic response at the plot and catchment scales .... Water Resour Res 40: W10202.

First synthetic modelling approach

2) Simulation with CATFLOW

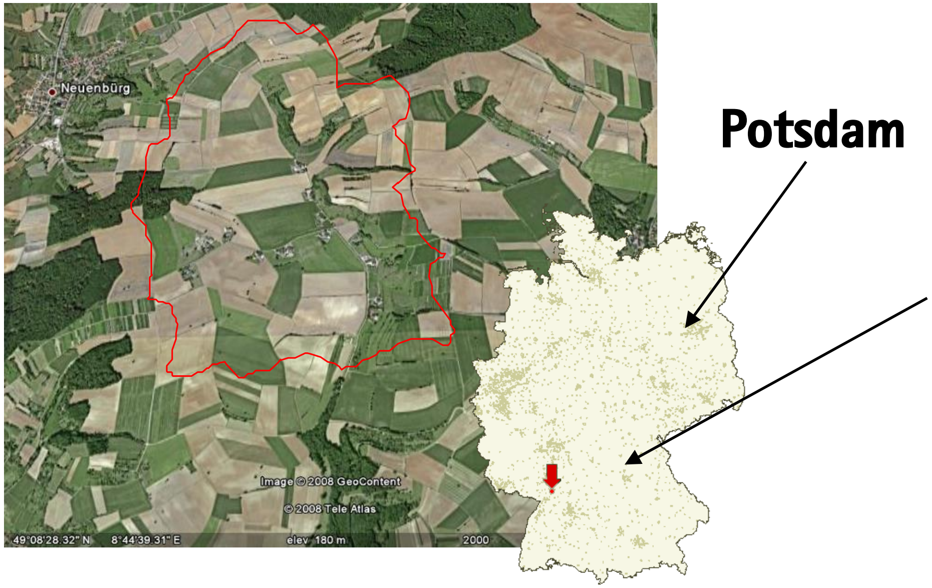


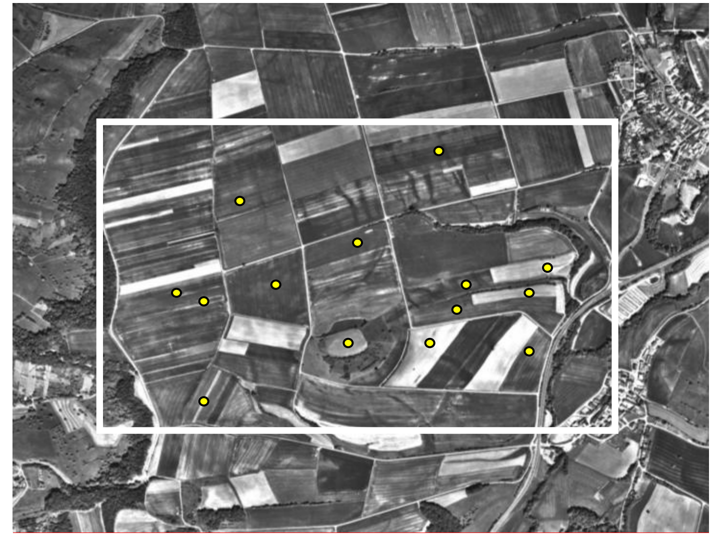
Erwin Zehe
Niklas Hartmann

Two study sites

Weiherbach

Hassberge





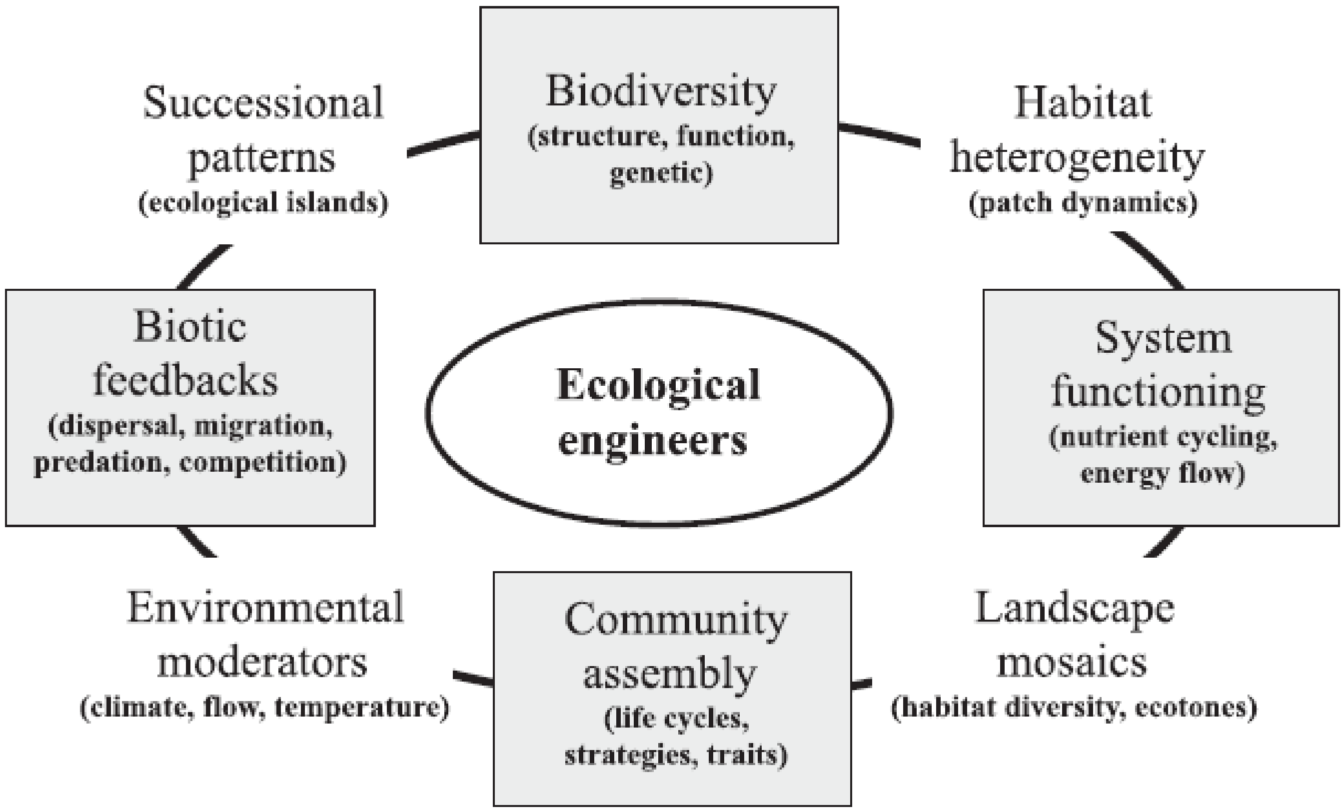
Loess soils with high erodibility and intensive agriculture.

Pelosol soils with high clay content and extensive agriculture, partly nature reserve

Protagonists

Ecosystem engineers / ecosystem engineering

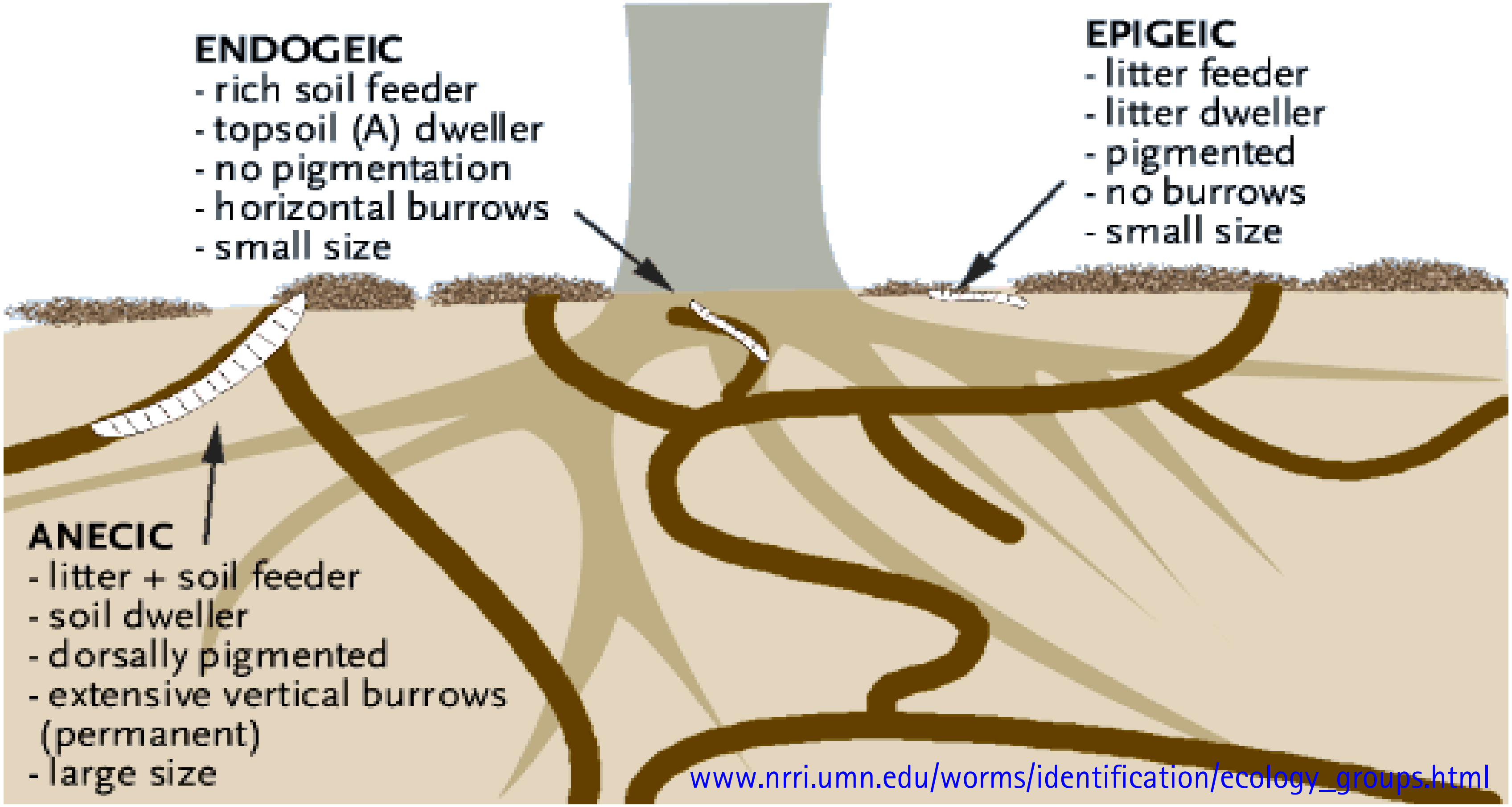
Abiotic and biotic effects of ecosystem engineers



Ecosystem engineers are organisms that directly or indirectly modulate the availability of resources to other organisms by causing physical state changes in biotic or abiotic materials.

Jones CG, Lawton JH & Shachak M 1994. Organisms as ecosystem engineers. - Oikos 69: 373-386.
Robinson, C. T., Tockner, K. and Ward, J. V. 2002. The fauna of dynamic riverine landscapes. - Freshwater Biology 47: 661-678.
Crooks JA 2002. Characterizing ecosystem-level consequences of biological invasions: the role of ecosystem engineers. - Oikos 97: 153-166.

Life forms (Bouché 1975)



Bouché MB, 1975. Action de la faune sur les états de la matière organique dans les écosystèmes. In: Kilbertius G, O. R, A. M, Cancela da Fonseca JA (eds.), Humification et biodégradation. Pierron, pp. 157-168.

ECOLOGY

Habitat factors

controlling earthworm distributions

Soil properties

Moisture

Nutrients, C/N

pH

Texture

Compaction

Land use

Vegetation

Organic layer

till vs no-till

Intensity

Earthworms

Climate

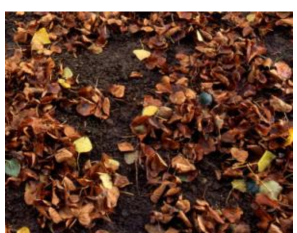
Temperature

Precipitation

Food

Org. matter

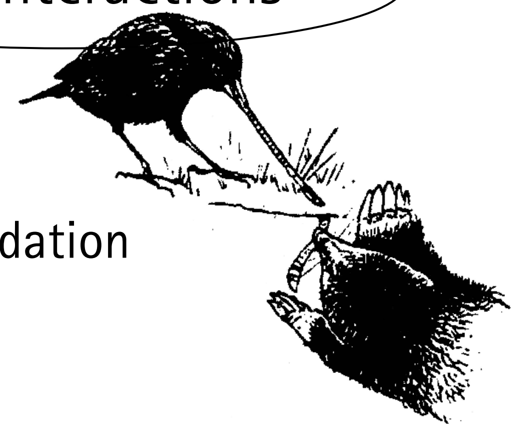
Vegetation / litter



Biotic interactions

Competition

Predation



BIOPORE

Modules 1/3

A) Hierarchical, multi-scale earthworm distribution model

Understanding and prediction of distribution patterns depending on soil, terrain and land use parameters ...

... and observational data

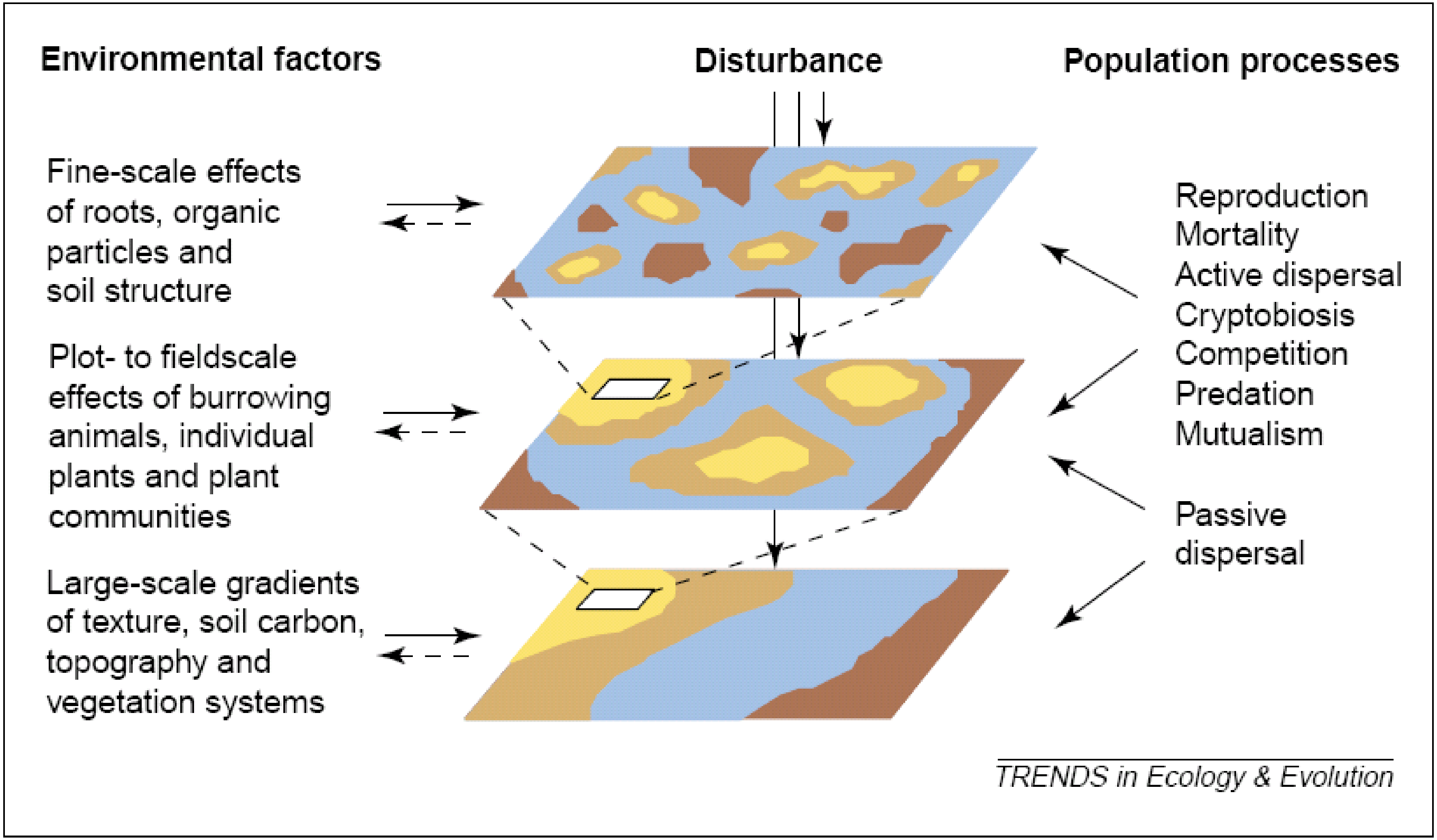
Earthworm extraction with mustard solution on a 50 × 50 cm^2 plots (stratified random sampling)

Counting macropores in different soil depths

Unbalanced nested sampling design to analyse spatial heterogeneity

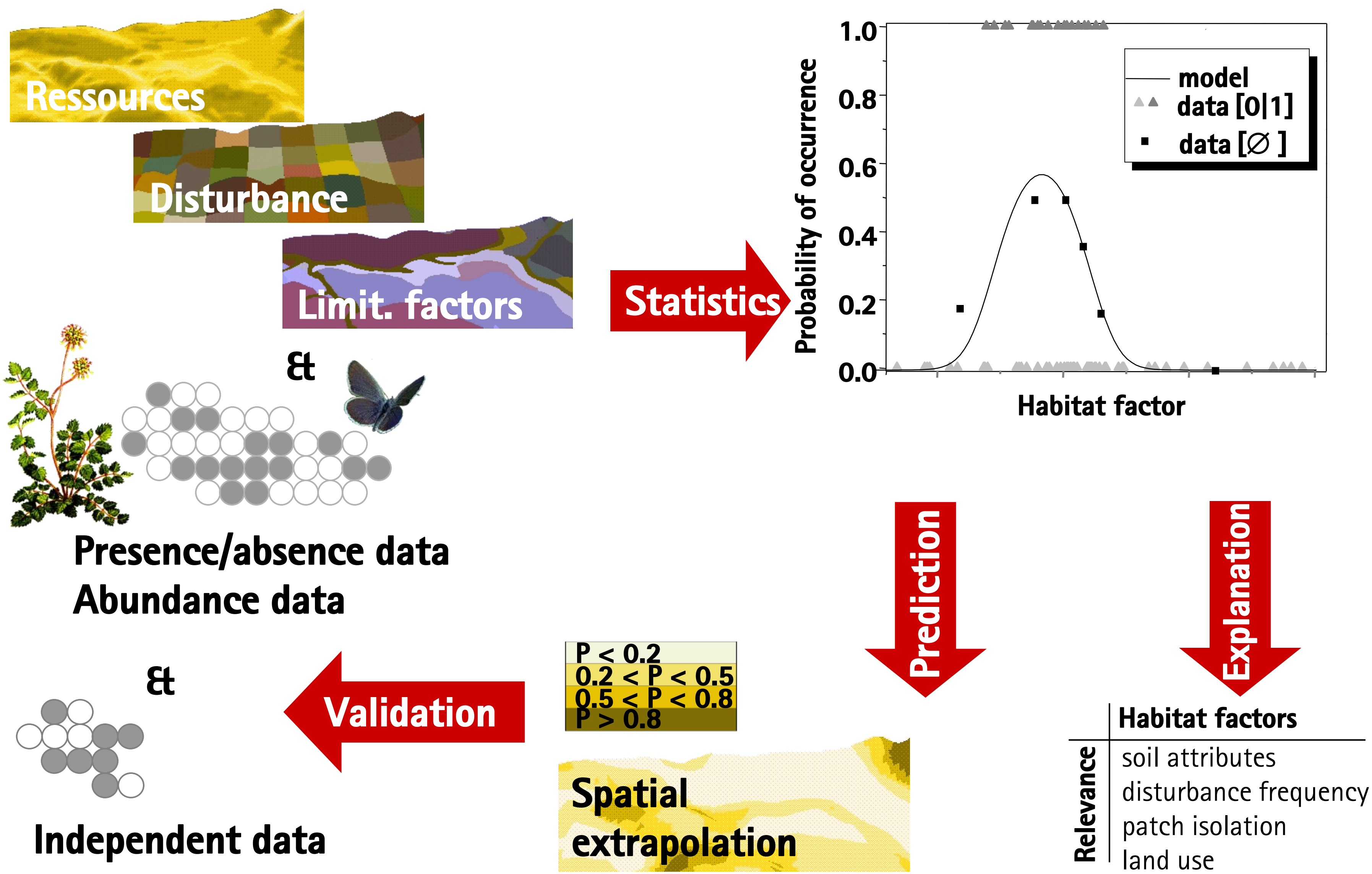
Schröder B, 2008. Challenges of species distribution modelling belowground. J Plant Nutr Soil Sci 171: 325-337.

Multi-scale spatial distribution of soil organisms



Ettema CH, Wardle DA, 2002. Spatial soil ecology. Trends Ecol Evol 17: 177-183.

Species distribution models / realised niche



Schröder B, 2008. Species in dynamic landscapes. Habil. Thesis, Potsdam University

Species distribution modelling – statistical methods

Standard /"Simple" methods

- Generalised linear models GLM ⬅
- Generalised additive models GAM
- Classification and regression trees CART

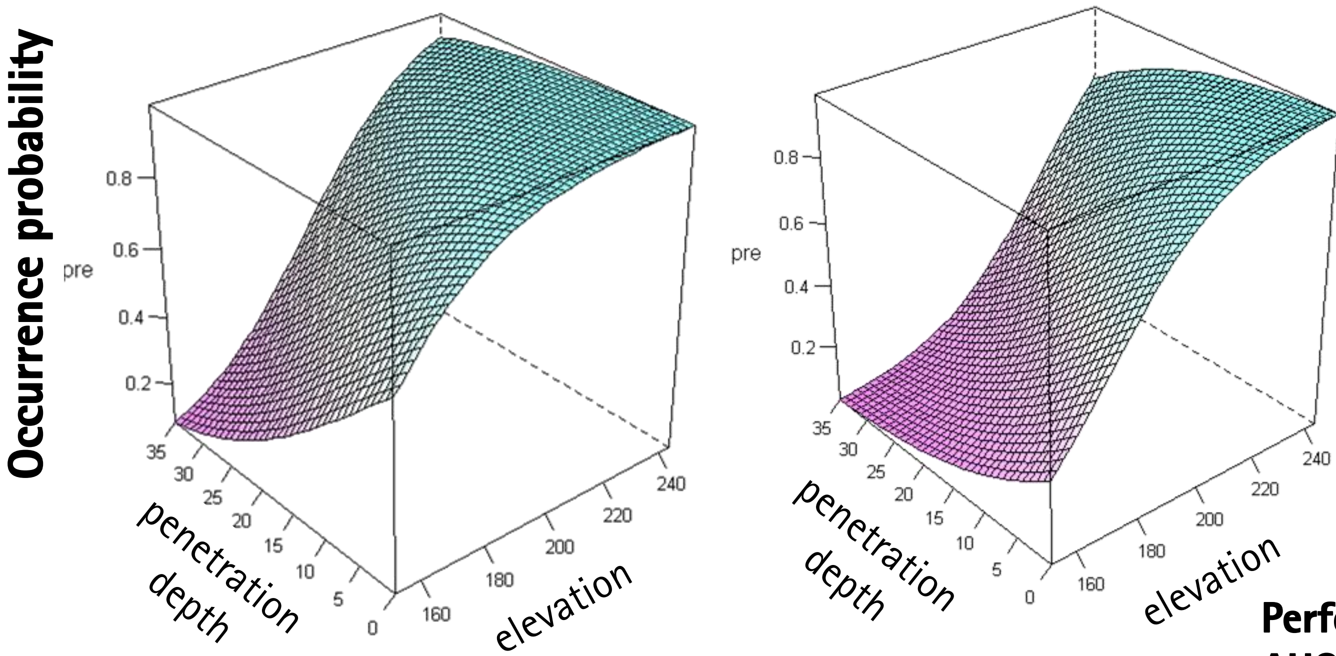
Ensemble forecasting methods (machine learning)

- Random Forest RF
- Boosted Regression Trees BRT ⬅
- Multivariate adaptive regression splines MARS

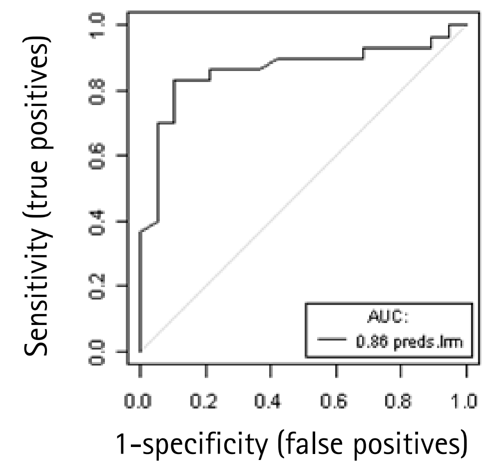
Several methods for variable selection, regularisation, multi-model inference
Internal validation via bootstrapping or crossvalidation or external
Check/controlling for residual spatial autocorrelation

SDMs – first results (simple logistic regressions)

without ploughing | **with ploughing**



Performance: ROC-plot
AUC = 0.86, R^2_N=0.43



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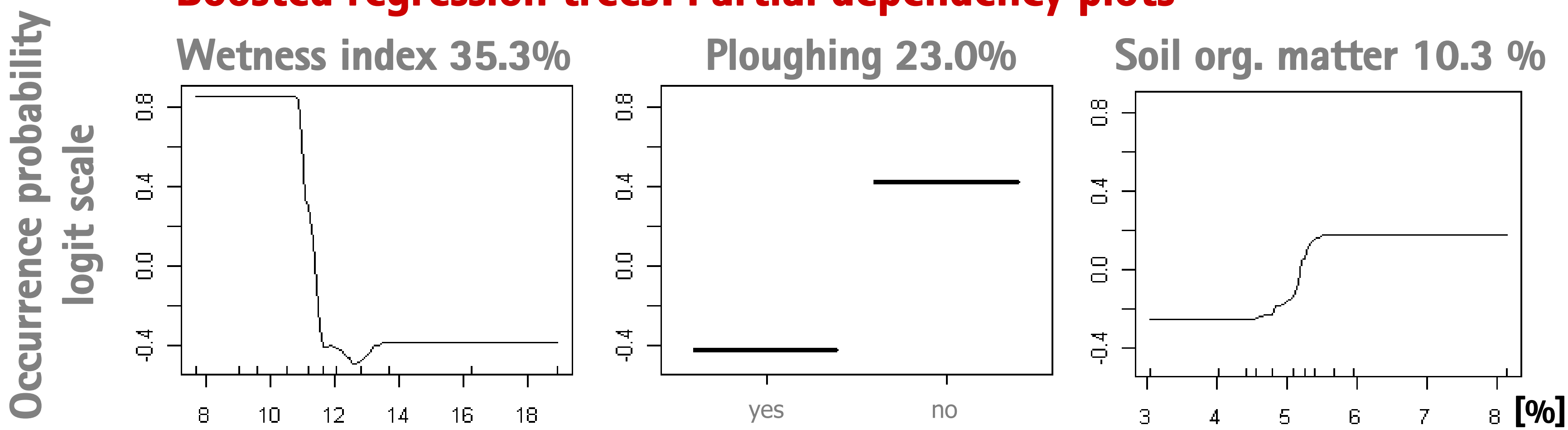
- Strong effect of land use practice (no-till > tillage)
- Low elevation = higher groundwater level
- Low penetration depth = soil compaction

Species distribution models – *Lumbricus terrestris*

Boosted regression trees: Partial dependency plots



Further predictors (contribution)

Heat load (9.2%)

pH (6.5%)

Compaction (6.0%)

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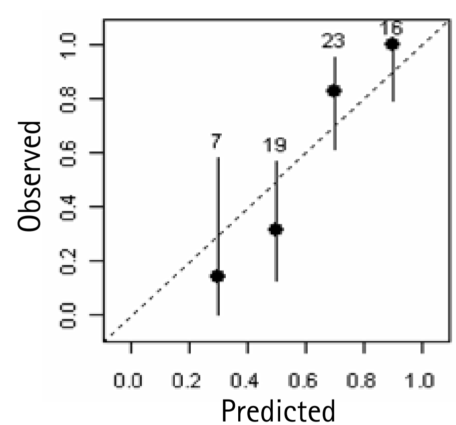
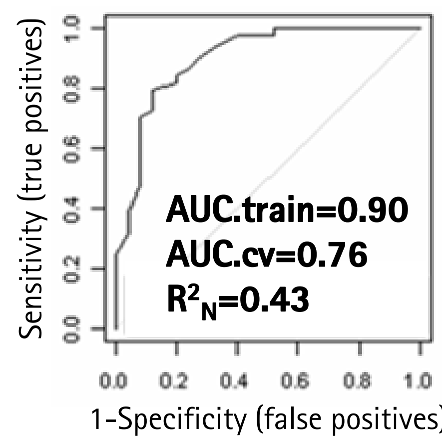
Higher occurrence probability in areas with low wetness index, no ploughing and higher soil organic matter content

Good model performance after cross-validation

Model performance





AUC = 0.5	: null model
0.8 ≤ AUC ≤ 0.9	: excellent
AUC = 1	: perfect classification

FIRST RESULTS

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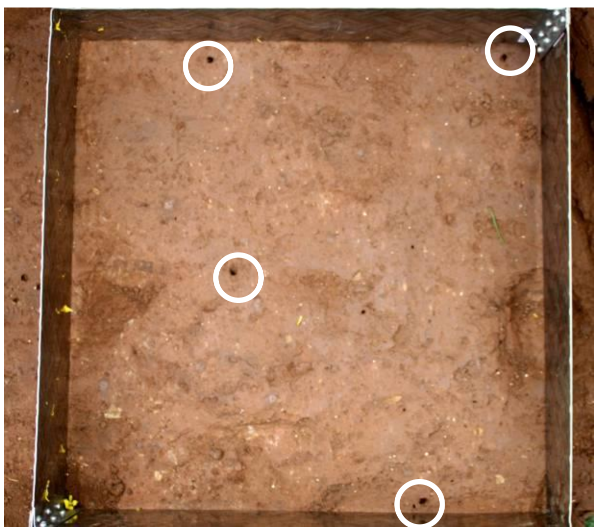
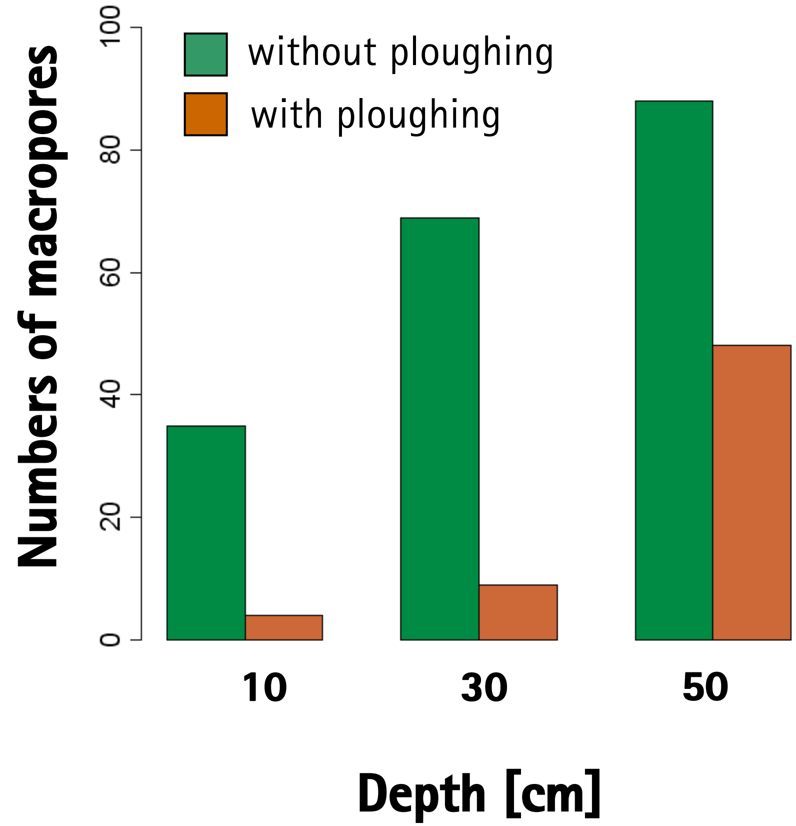
Macropores





Modules 2/3

Stage-structured population dynamic model

Understanding and prediction of population dynamics of anecic earthworms …

… depending on soil properties (temperature, moisture), resource availability and disturbance (land use)

… considering active and passive dispersal

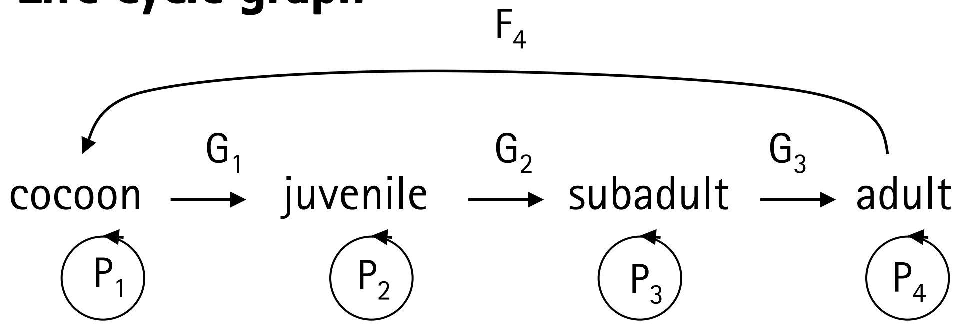
Matrix population models (Klok et al. 1997; Pelosi et al. 2008), dynamic energy budget model (Jager et al. 2006)

Pelosi Cet al. 2008. WORMDYN: A model of *Lumbricus terrestris* population dynamics in agricultural fields. Ecol Model 218: 219-234.
Jager T, Reinecke SA, Reinecke AJ, 2006. Using process-based modelling to analyse earthworm life cycles. Soil Biol Biochem 38: 1-6.
Klok C et al. 1997. Assessing the effects of abiotic environmental stress on population growth in *Lumbricus rubellus*. SBB 29: 287-293.

APPROACH

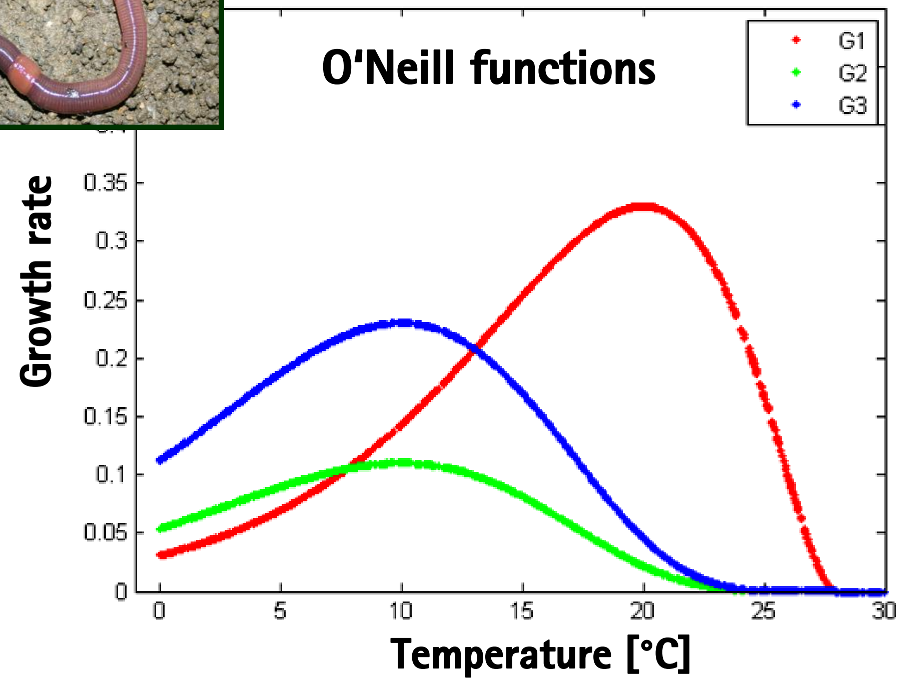
Life cycle graph – stage-structured population model

Life cycle graph



Transition matrix

$$M = \begin{pmatrix} P_1 & 0 & 0 & F_4(T) \\ G_1(T,\theta) & P_2 & 0 & 0 \\ 0 & G_2(T,\theta) & P_3 & 0 \\ 0 & 0 & G_3(T,\theta) & P_4 \end{pmatrix}$$



Simulation model

$$n_{t+1} = M(T,\theta)_t \cdot n_t$$

Implementation: Anett Schibalski

Pagel J, Fritzsch K, Biedermann R, Schröder B, 2008. Annual plants under cyclic disturbance regimes ...Ecol Appl 18: 2000-2015.
Söndgerath D, Schröder B, 2002. Population dynamics and habitat connectivity affecting spatial spread .... Landscape Ecol 17: 57-70.

B I O P O R E

Modules 3/3

C) Stochastic transport model

Predicting infiltration, transport and sorption of tracers and pesticides ...

... depending on spatiotemporal distribution of connective macropores (earthworm burrows).

CATFLOW

Loes van Schaik
Erwin Zehe
Julian Klaus

Maurer T, 1997. Physikalisch begründete, zeitkontinuierliche Modellierung des Wassertransports in kleinen ländlichen Einzugsgebieten. PhD thesis, Universität Karlsruhe

Zehe E, Flühler H, 2001. Slope scale distribution of flow patterns in soil profiles. J Hydrol 247: 116-132.

BIOPORE

Summary

Results from previous projects show

a) Strong effects of earthworm burrows on transport of pesticides
b) Strong need for an integrated ecohydrological modelling approach

Preliminary results show

a) Importance of management (no-till) for earthworm distribution
b) Strong effect of soil moisture and temperature on earthworm abundance
c) High spatial and seasonal variability in earthworm abundances at both sites
d) Significant preferential flow at both study sites

... still a long way to go ...