Land sparing or sharing or something in between?

Multi-objective land use optimization based on scenario analysis

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SWAT2018 Conference, Brussels

Multiple demands on agricultural landscapes

Production

Food

Bioenergy

Water

Water quality

Groundwater recharge

Environmental flow

Hydropower

Recreation

Active

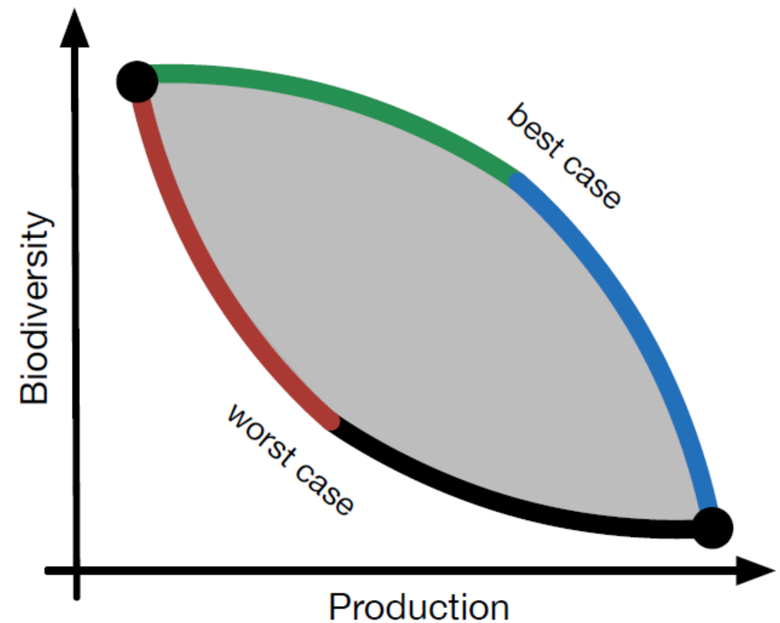
Passive

Biodiversity

Species richness

Functional diversity

Trade-offs



Land use intensity and landscape configuration

Land sparing

vs.

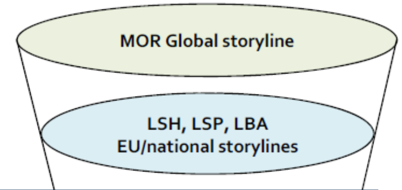
Land sharing

Land sharing/sparing debate, e.g.:

Phalan et al. / *Science* 333 (2015), 1289-1291

Von Wehrden et al. / *Landscape Ecol* 29 (2014), 941–948

Workflow



Common storylines
for land sharing,
land sparing,
and business as usual

Scenario development
(stakeholder discussion)

Parameter	Einheit	Heute	LBA	LSP	LSH
Landnutzung					
Siedlung/Verkehr	Gesamt - Fläche	10.1	12.5	10	10.9
Ackerland		53.9	49.1	58	52
Dauerkulturen/Streuobst		0.8	0.8	1.5	0.8
Wald		19.6	22	25	22
Grünland - intensiv		6.8	6.8	5	0
Grünland - extensiv		7	7	0	13.8
Feuchtgebiete		0.1	0.1	0.1	0.1
Vegetationslos (z.B. Tagebau)		0.4	0.4	0.4	0.4
Schutzgebiete		48.5	48.5	51.5	48.5
Naturschutzfachlich hochwertige Agrarflächen					
Landnutzung					
Fruchtarten:	% Acker-fläche				
Wintergerste		15.6	15.6	8	17
Winterroggen		3.1	3.1	0	5
Winterweizen		36.1	41.1	41.5	41
Winterraps		22.6	18	27.5	5
Mais		14	16.5	18	20
Zuckerrübe		2.3	2.3	5	1
Sommergerste		1.4	1.4	0	1
Ackergras		3.8	2	0	6
Alfalfa		1.1	0	0	4
Bodenbearbeitung:					
konventionell		40	30	40	0
konservierend		60	70	60	100
Gründüngung		0.4	0.8	0	5
Bioanbau		4	5	0	20
Düngeintensität auf Acker:					
N	kg/ha	151	140	166	100
P		43	40	47	40

Spatial targeting of management options

Scenario simulations

SWAT
crop yield, runoff, water quality

Biodiversity model
bird species distribution

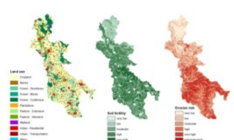
Multi-objective optimization

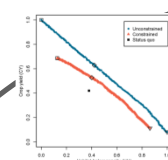
CoMOLA

Linking **SWAT**, **biodiversity model** with **NSGAII**

GitHub

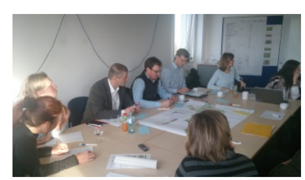
Result
Scenario impacts
on ESS and biodiversity





Result
Landscape potential
(trade-off curves)

Comparison
Where can we be more efficient with measures?



biodiversa TALE UFZ

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Bodenbearbeitung:					
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konservierend		60	70		
Gründüngung		0.4			
Bioanbau					
Düngeintensität auf Acker:					
N					
P					

Scenario development
(stakeholder discussion)

MOR Global storyline

LSH, LSP, LBA
EU/national storylines

Common storylines
for land sharing,
land sparing,
and business as usual

Procedure and examples in the *TALE Learning Environment*

tale.environmentalgeography.nl

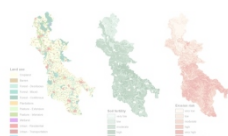
crop yield, ru

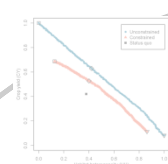
Biodiversity model
bird species distribution

Biodiversity model with
NSGAII

GitHub

Result
Scenario impacts
on ESS and biodiversity





Result
Landscape potential
(trade-off curves)

Comparison
Where can we be more
efficient with measures?

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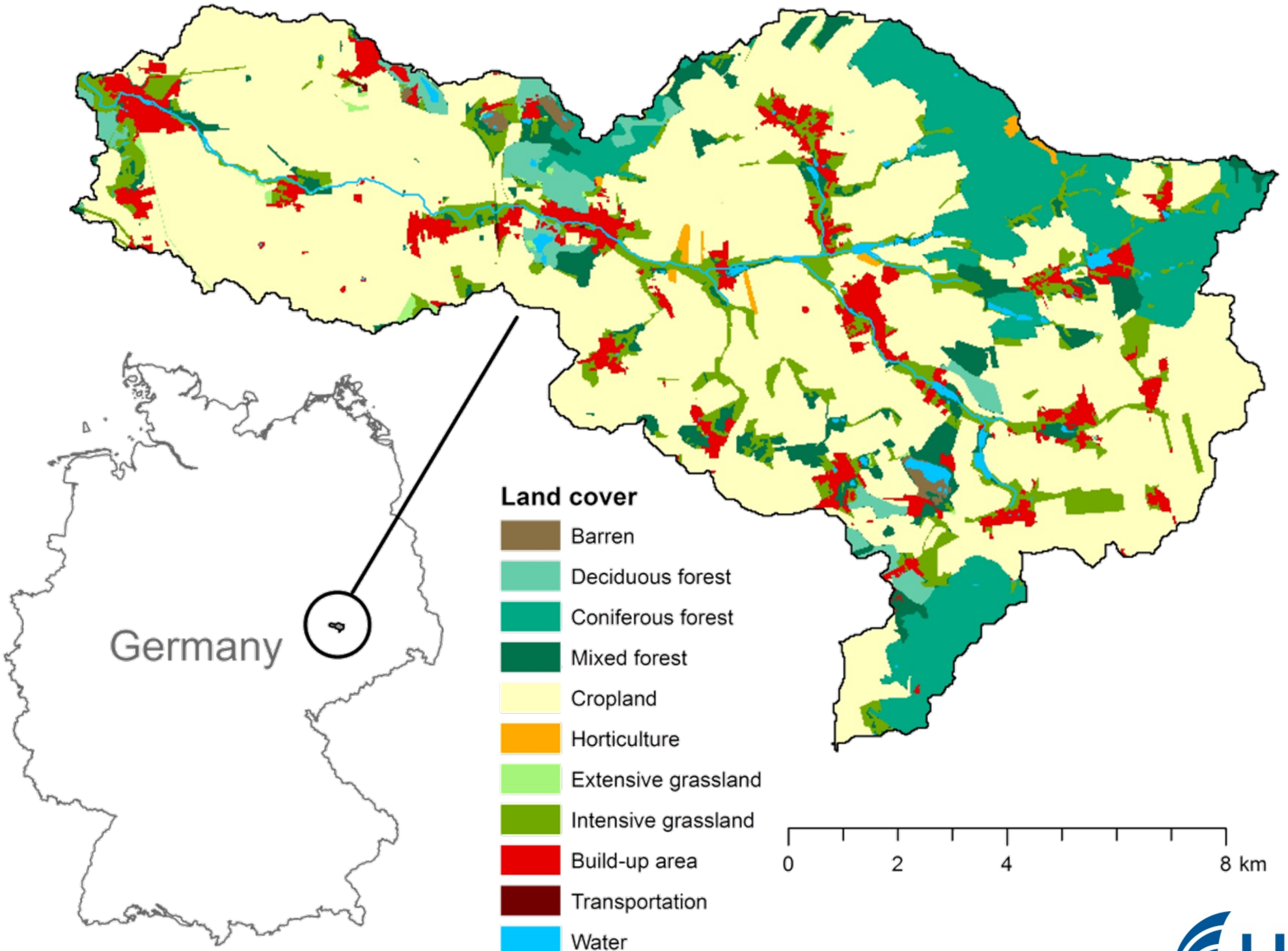
Study area

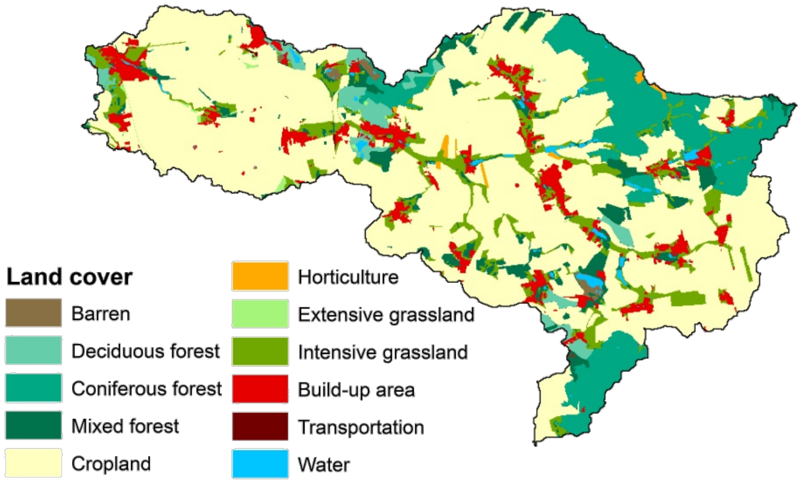
Lossa River Basin (141 km²)



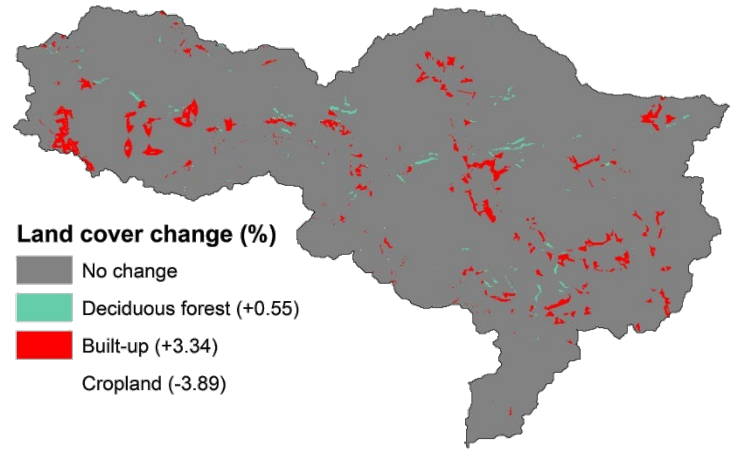
Study area: Lossa River Basin

Spatially explicit land cover changes

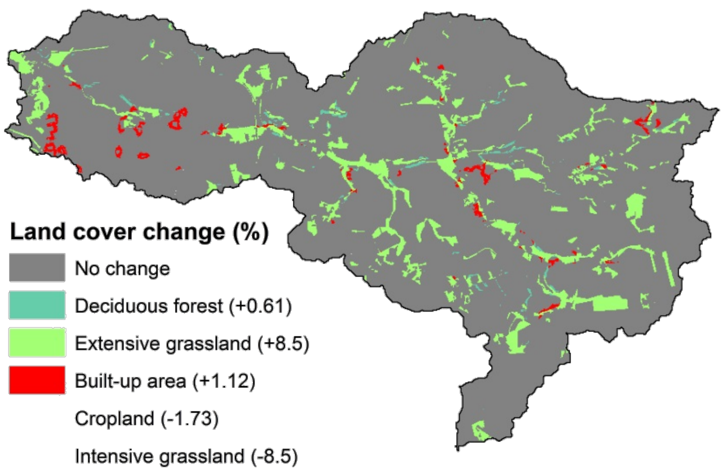
Current



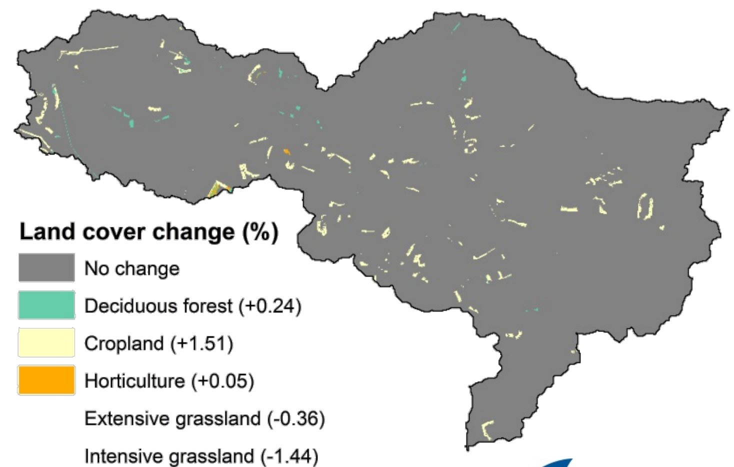
Business as usual



Land sharing



Land sparing



General land cover /land use changes

	Current	B. as usual	Land sharing	Land sparing
Crop rotations	According to crop statistics	Slightly less diverse	Slightly more diverse	Strongly less diverse
Org. farming (%)	4	5	20	0
Fertilizer (kg N/P)	112/31	105/36	81/30	122/39
Tillage (% conserv.)	60	70	100	60
Linear elements (e.g. hedges)	According to land use map	No change	Increase	Decrease

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Models

1) Soil and Water Assessment Tool (SWAT)

- **Process-based** integrated watershed model
- Calibrated and validated for **streamflow**, **total loads of nitrogen**, **phosphorus** and **suspended solids** as well as **crop yields**
- Basin-wide **agricultural gross margin** (in €) calculated from simulated crop yields and crop-specific costs and market prices

2) Bird habitat model

- Nine **Random Forest models**, one for each of the nine observed bird species breeding in agricultural sites of the Lossa Basin
- Taking into account **up to 21 predictor variables** (climate, soil, land use, linear elements and distance parameters)
- Output: **suitable habitat for each of nine species**

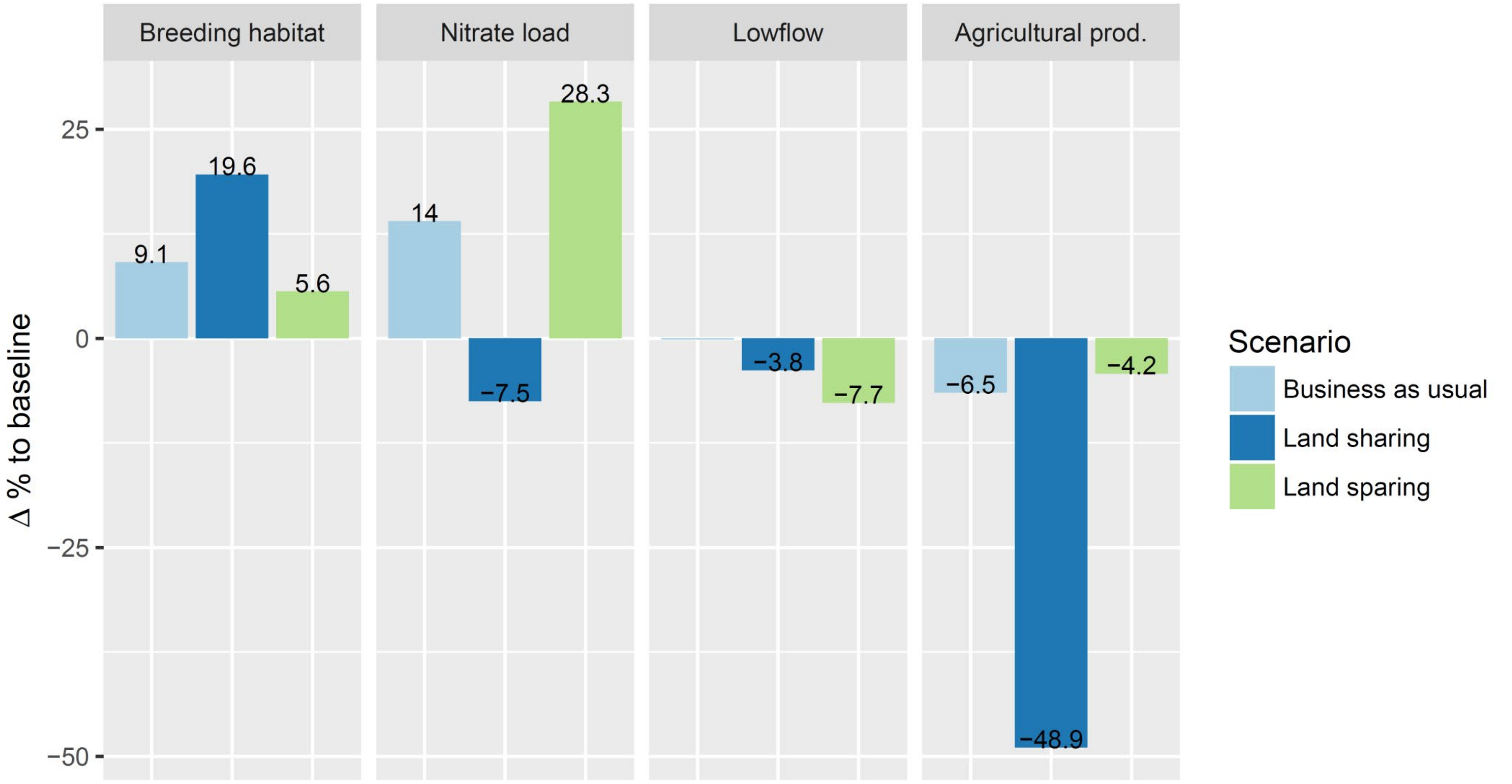




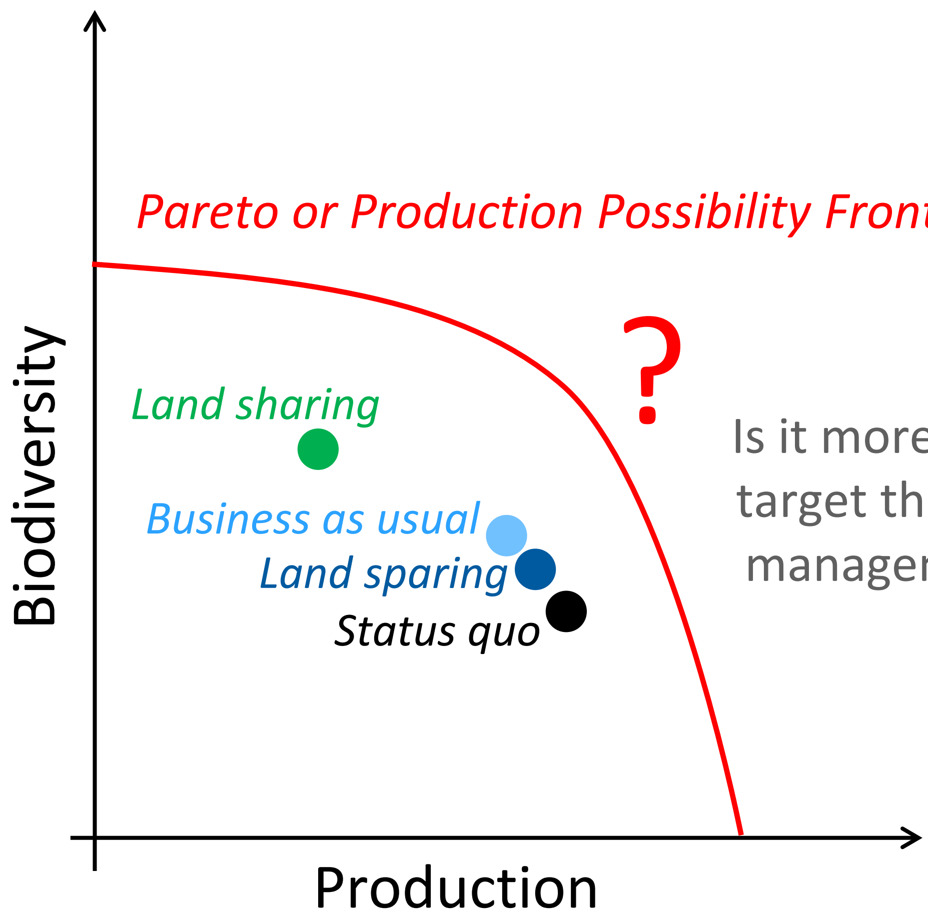




Results

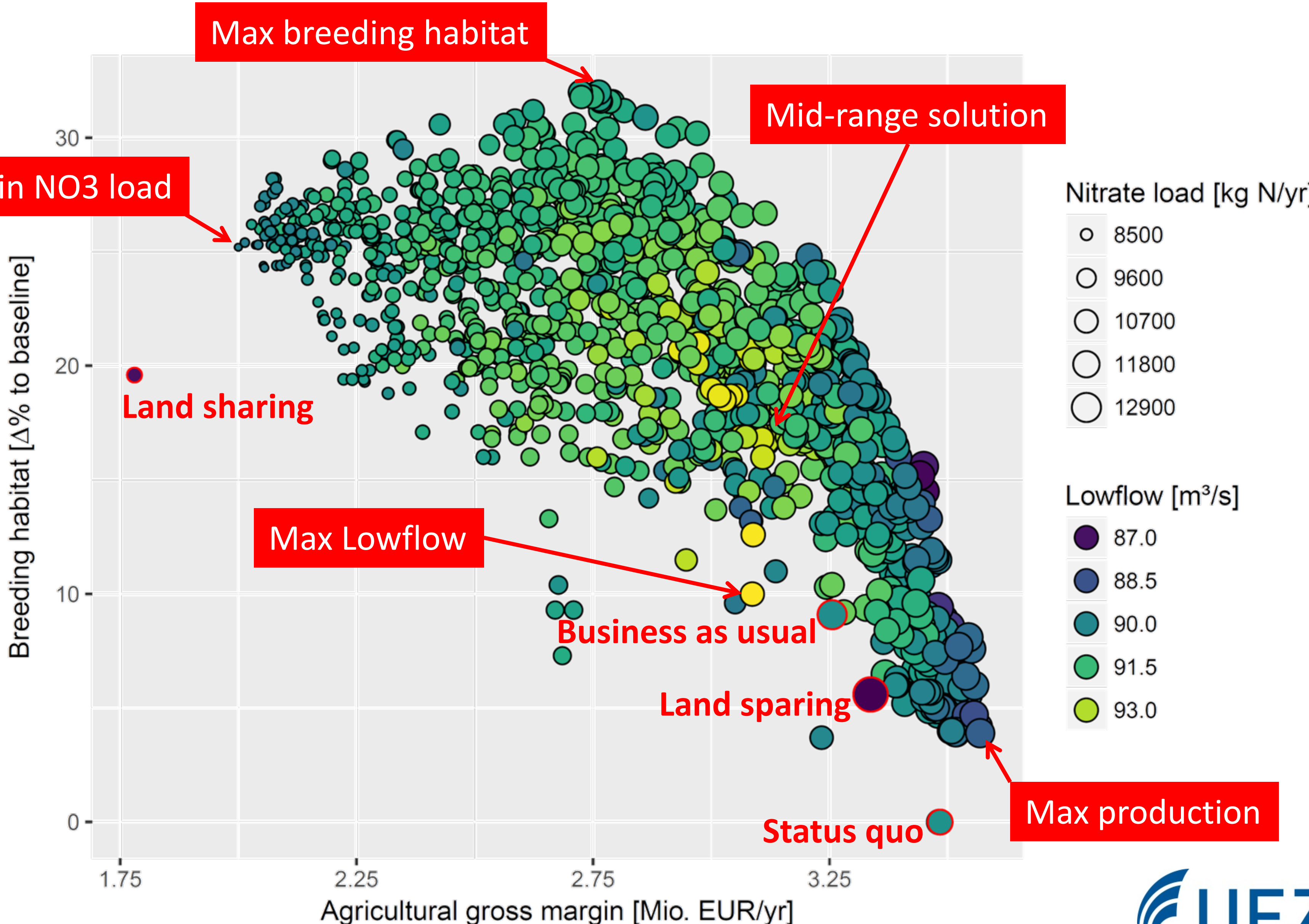

Breeding habitat
Nitrate load
Lowflow
Agricultural prod.
25
0
−25
−50
Δ % to baseline
9.1
19.6
5.6
14
−7.5
28.3
−3.8
−7.7
−6.5
−48.9
−4.2
Scenario
Business as usual
Land sharing
Land sparing

Multi-objective optimization beyond scenario analysis



Is it more effective to spatially target the different land use / management options at HRU level?

Optimization

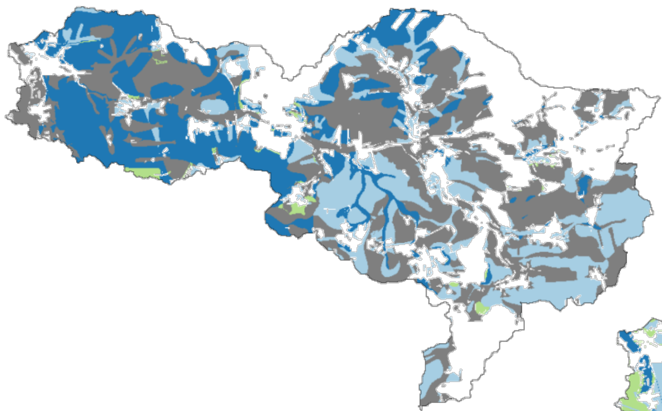


Optimization

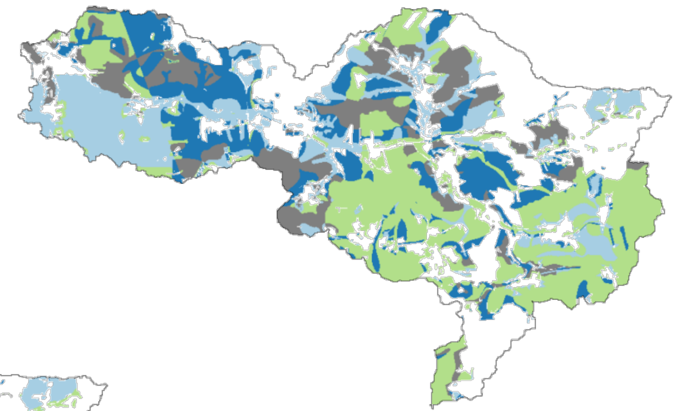
Land cover/use according to:

- Status quo
- Business as usual
- Land sharing
- Land sparing

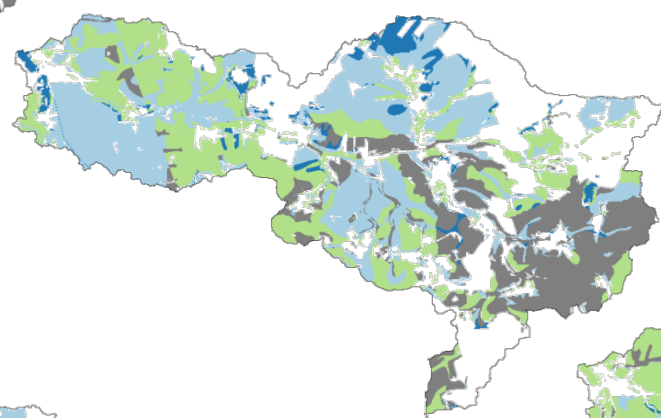
Max production



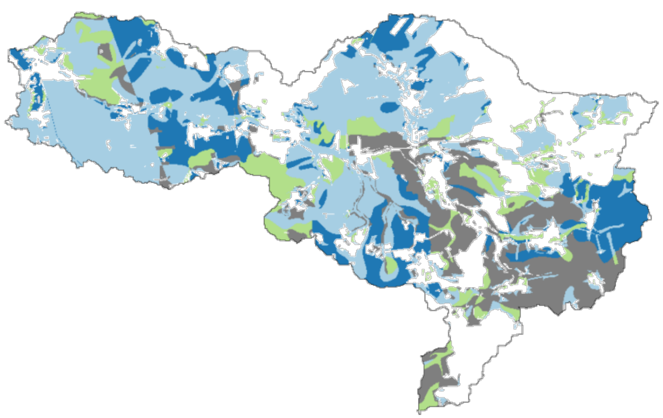
Max breeding habitat



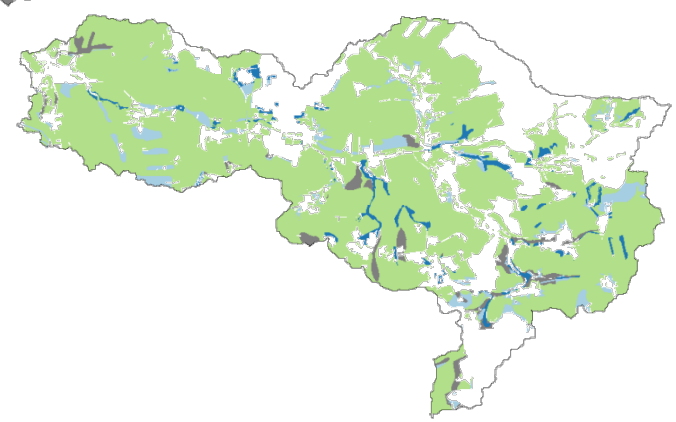
Mid-range solution



Max lowflow



Min NO3 load



Analysis of optimization results

Why did those land cover/management patterns emerge?

=> spatial factor analysis

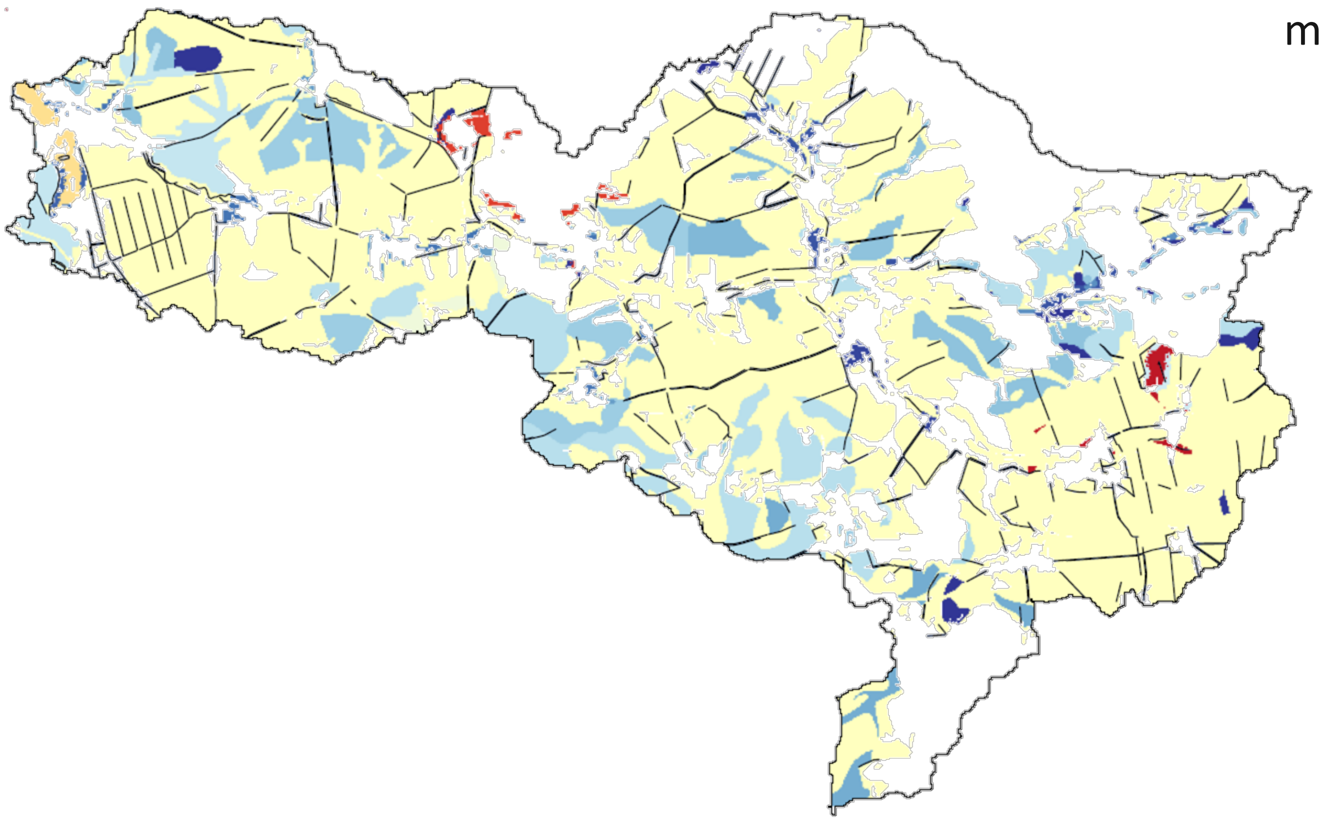
Which solutions are preferred?

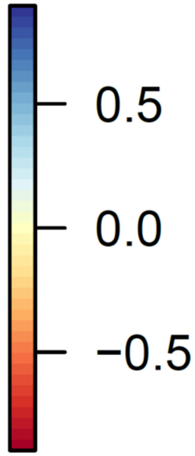
=> involve stakeholders

Which specific management recommendations can be derived?

=> visualize allocation of single measures

Suggestion according to mid-range solution:





Δ change of linE area compared to status quo [% of HRU area]

Conclusions

- **Scenario analysis** revealed trade-offs among agricultural production and biodiversity (and water quality)
- **Multi-objective optimization** of land use at HRU level as a way **to minimize the trade-offs** (non-dominated solutions outperform stakeholder-based scenarios for land sharing and land sparing)
- **Challenging**: In-depth-analysis and **interpretation** of results as well as illustration of model **uncertainties**
- **Food for discussion** with stakeholders and decision-makers **on „where to put things"** in landscapes to optimally provide multiple ecosystem services and biodiversity at the same time


Tide
7.44
4.07
Deep Heat
Sun
Window of Human Economy
Ocean
Material Cycles
Land
Commerce Industry
Human
Shared Information
Geobiosphere
E20 Solar emjoules/year
Increasing Transformity
= Money
M.Volk '13

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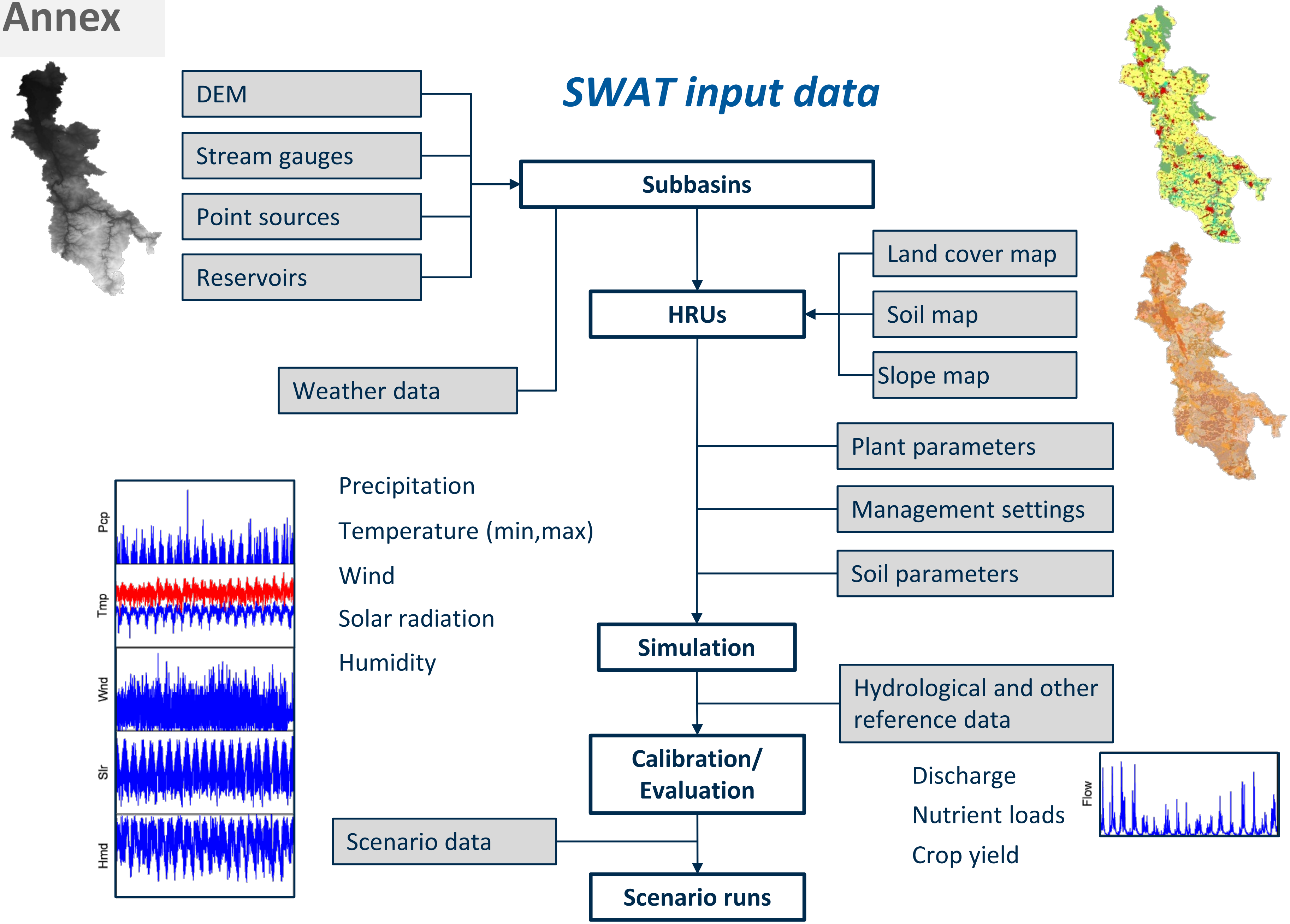
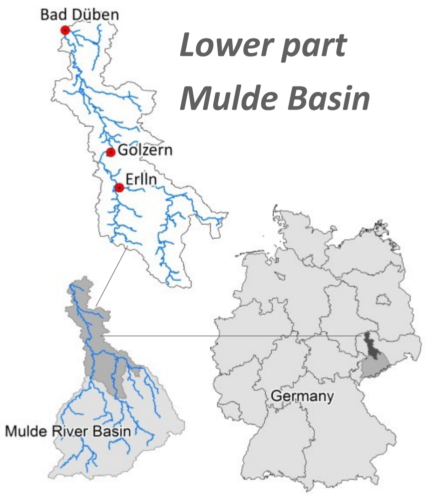
Annex

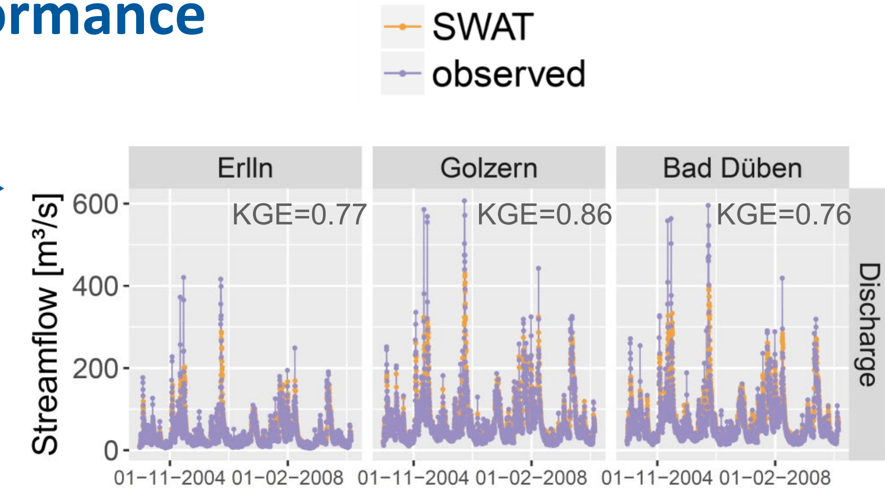

SWAT input data
DEM
Stream gauges
Point sources
Reservoirs
Subbasins
HRUs
Land cover map
Soil map
Slope map
Weather data
Plant parameters
Management settings
Soil parameters
Pcp
Tmp
Wnd
Slr
Hmd
Precipitation
Temperature (min,max)
Wind
Solar radiation
Humidity
Simulation
Hydrological and other reference data
Calibration/ Evaluation
Discharge
Nutrient loads
Crop yield
Flow
Scenario data
Scenario runs

Annex

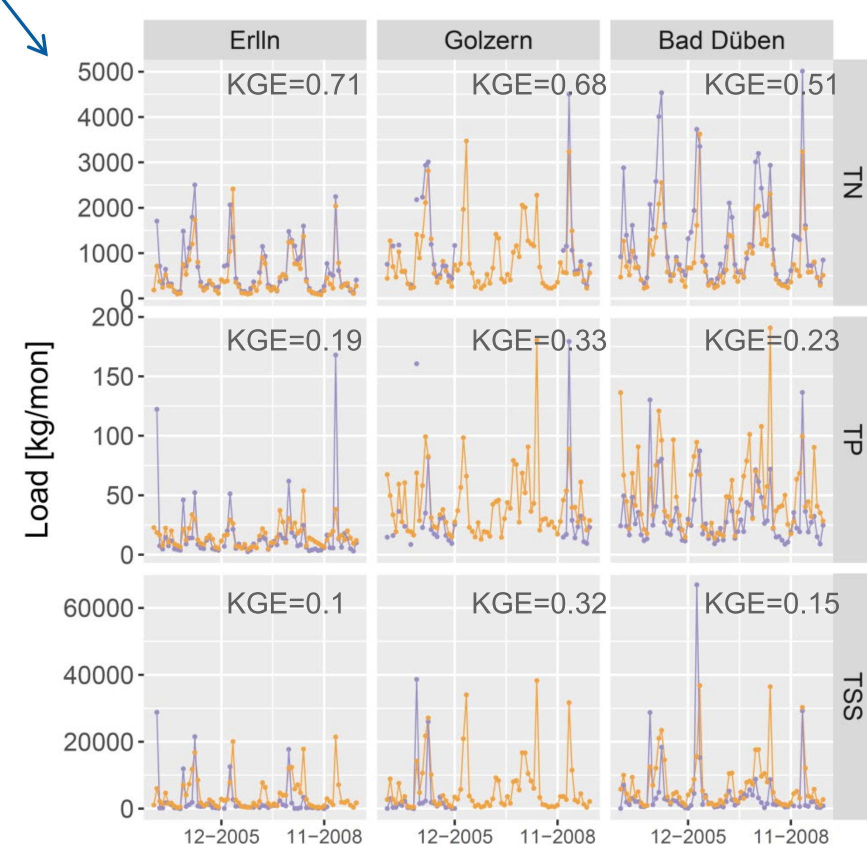
SWAT model performance



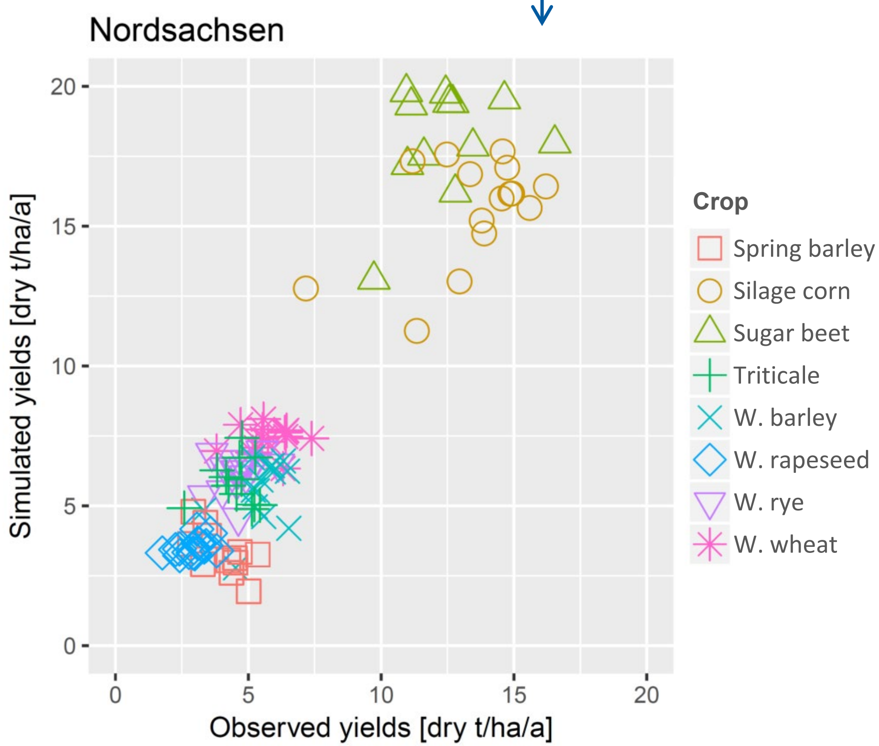
Streamflow



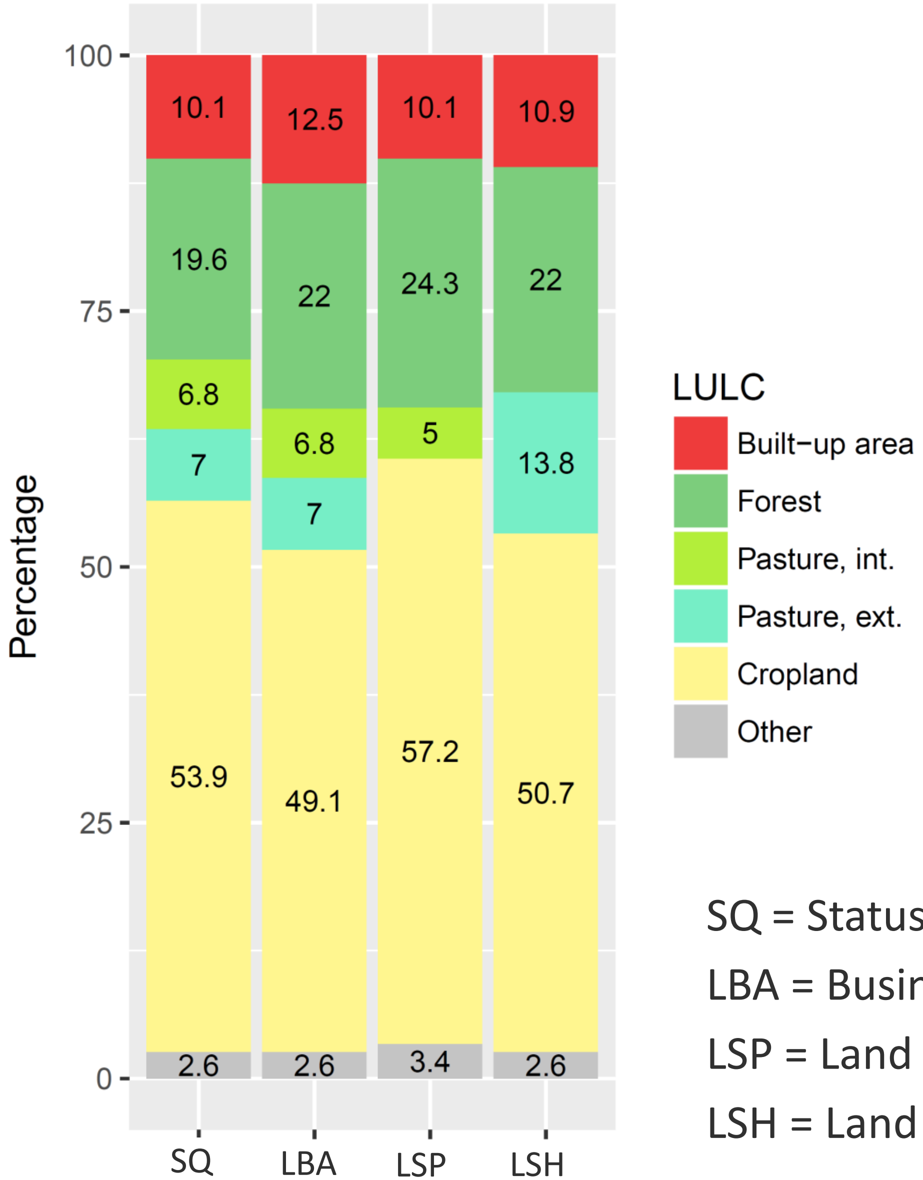
Water quality

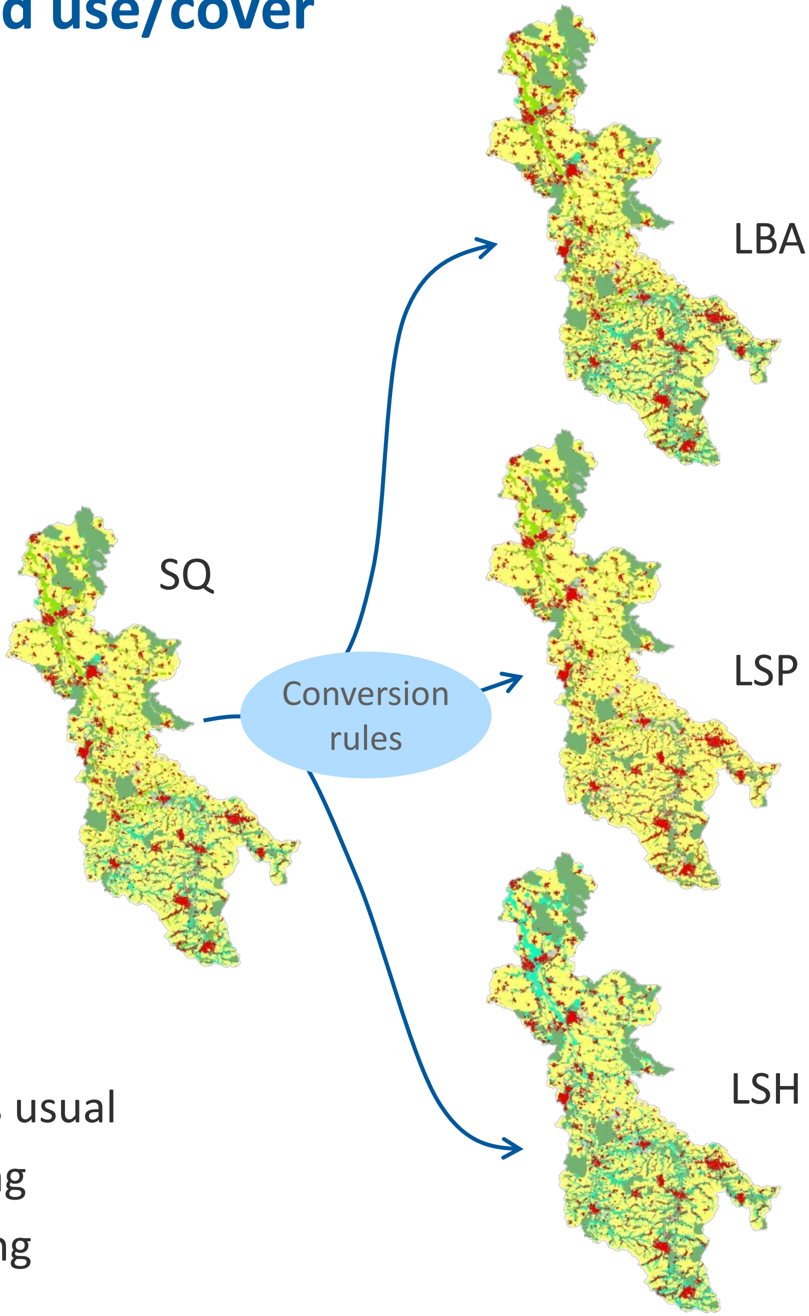


Crop yield



Scenario Design: Land use/cover





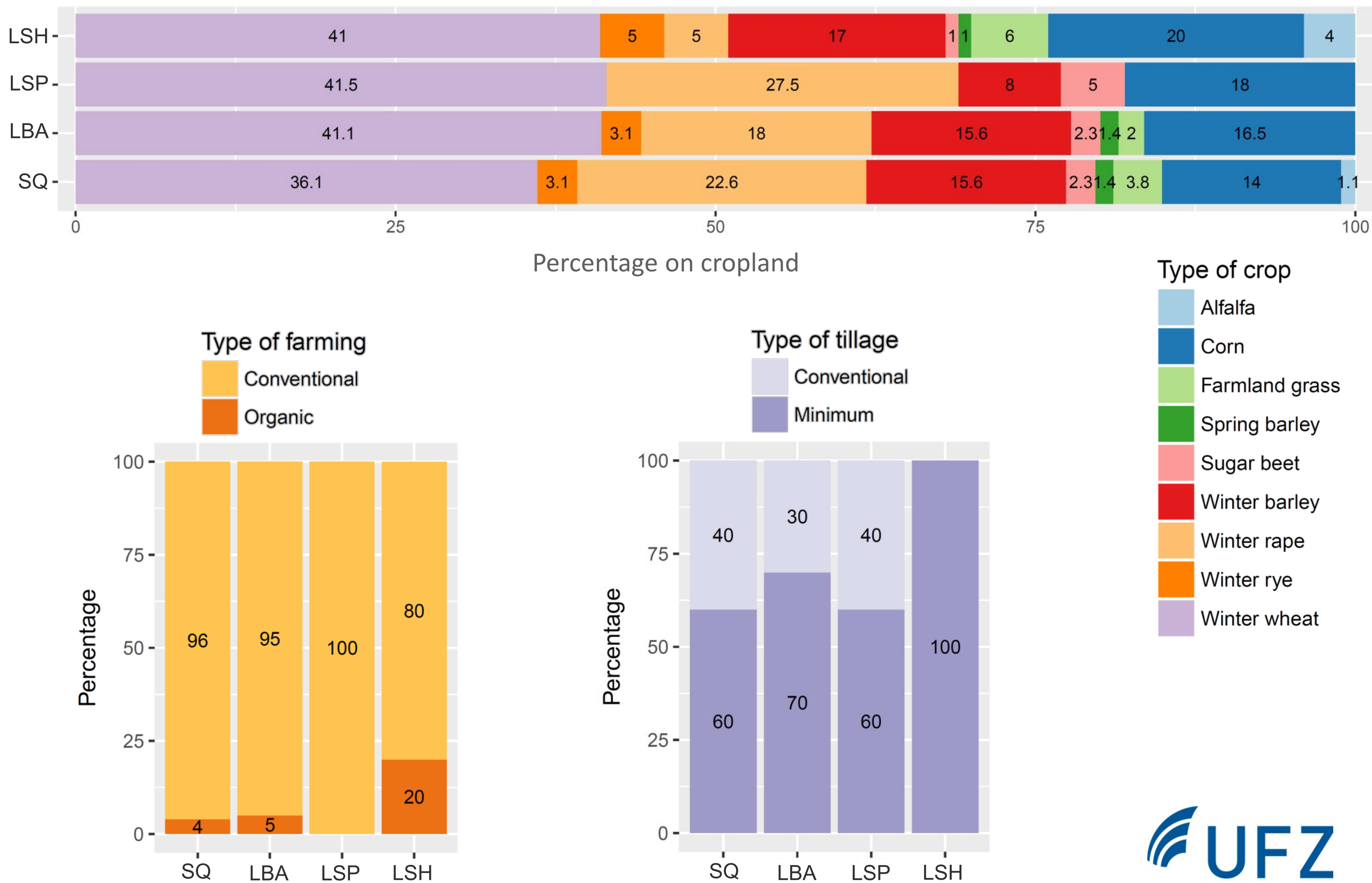
SQ = Status quo

LBA = Business as usual

LSP = Land Sparing

LSH = Land Sharing

Scenario Design: Agricultural management



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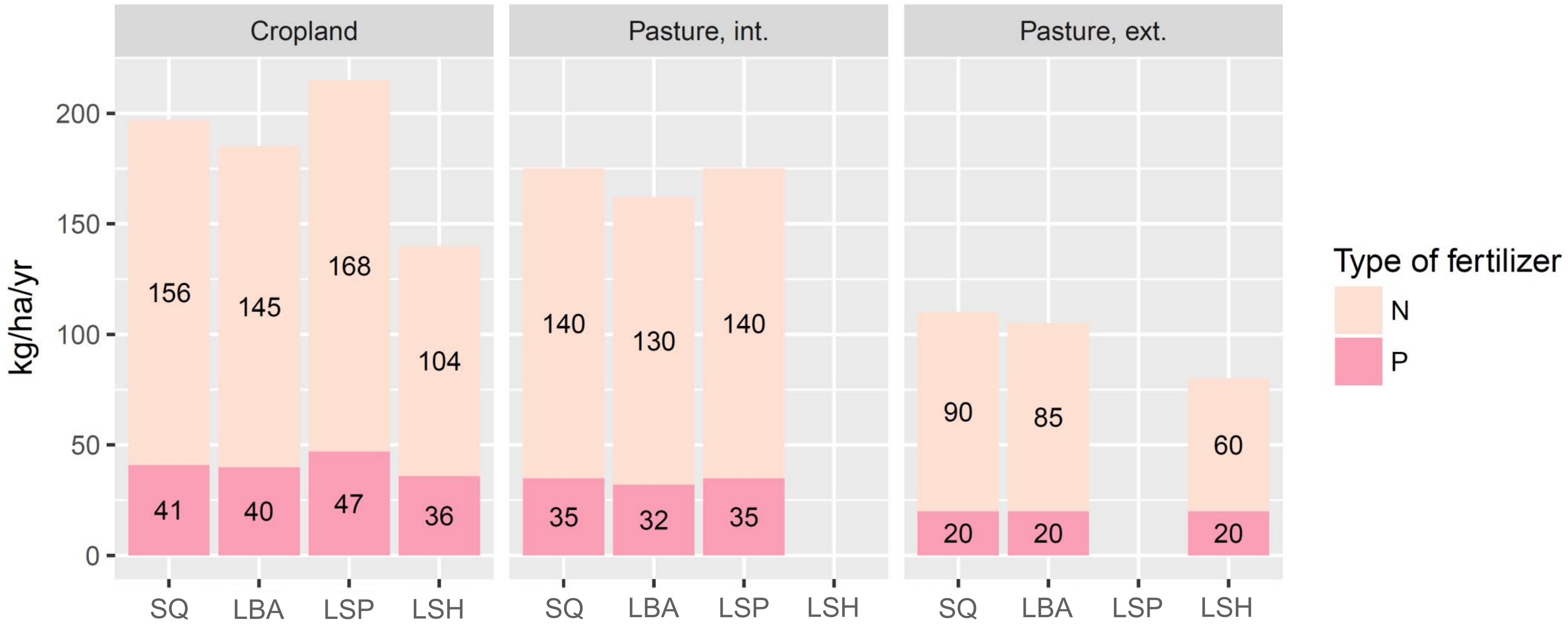
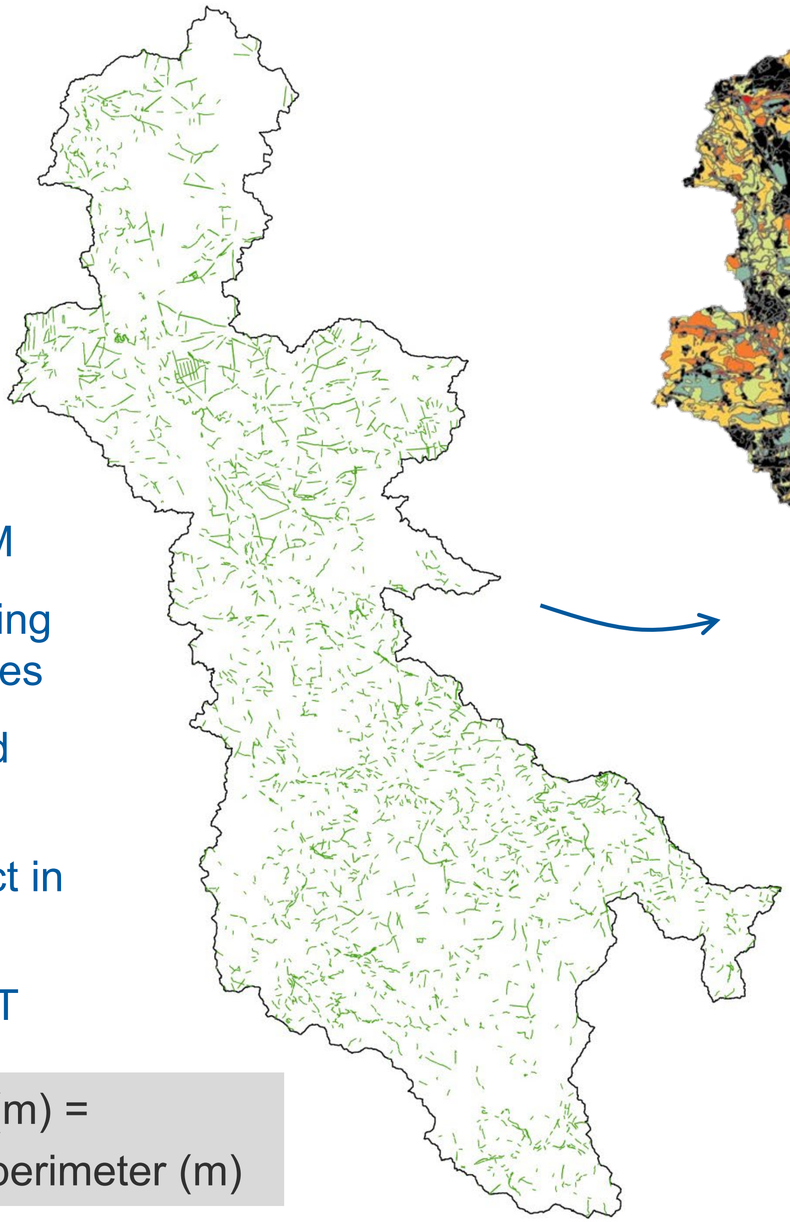
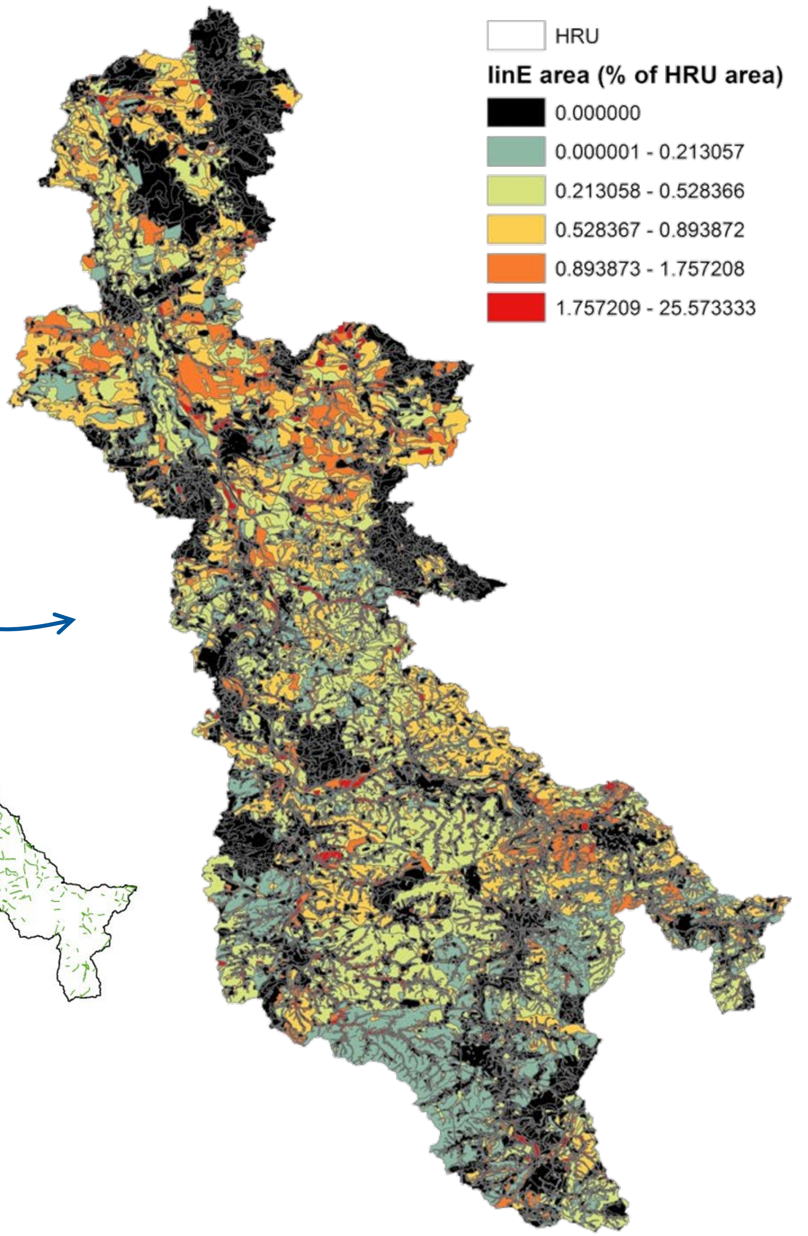


Scenario Design: Linear elements (linE)





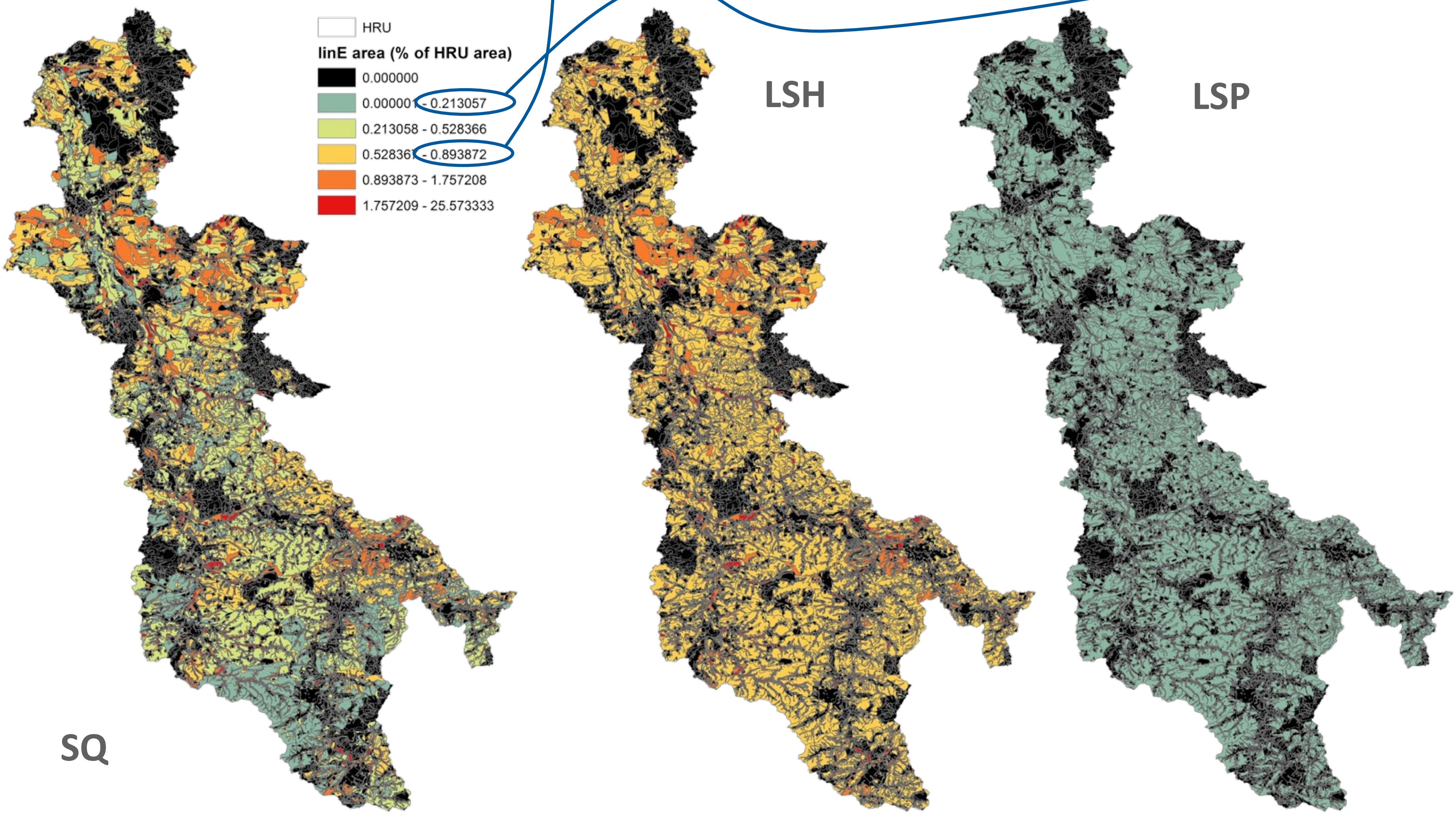
- Source: ATKIS-DLM
- Polylines representing tree rows and hedges
- 2.5m buffer overlaid with HRU map
- Habitat quality effect in Biodiv models
- Filter effect in SWAT

HRU filter strip width (m) =
linE area (m²) / HRU perimeter (m)

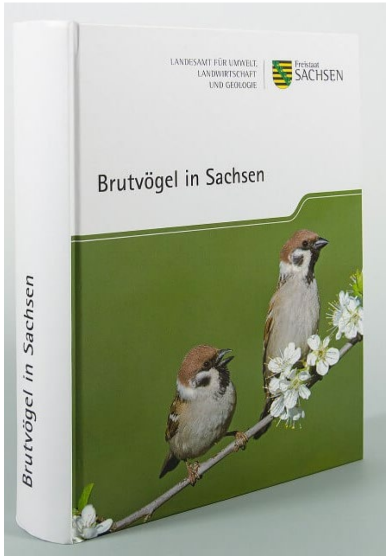
Scenario Design: Linear elements (linE)

Min for LSH: Upper quartile of SQ

Max for LSP: Median of SQ



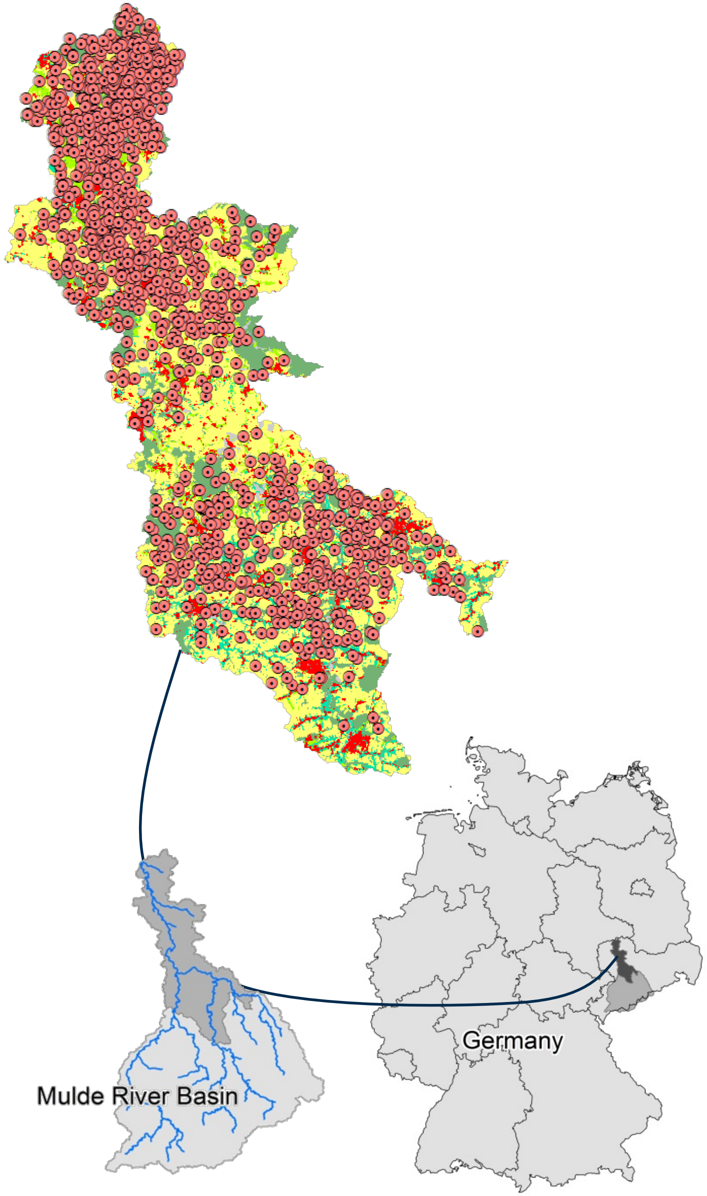
Biodiversity on the example of birds



Breeding birds dataset from Saxon State Agency of Environment, Agriculture and Geology (LfULG)

↓

13 species with sufficient number of observations **for modeling** of breeding habitat **within** the **lower part of the Mulde River basin**



Predictor variables

Land use (within a radius of 250 m)

- Urban
- Transportation
- Cropland
- Pasture (total, extensive, intensive)
- Forest (total, deciduous, coniferous, mixed)
- Horticulture
- Wetlands
- Water
- Barren

Soil

- Available water capacity
- Bulk density
- Carbon content
- Satur. hydraulic conductivity

Linear elements

- Share on HRU area
- Share on HRU perimeter
- Forest edges

Distance parameters

Distance to:

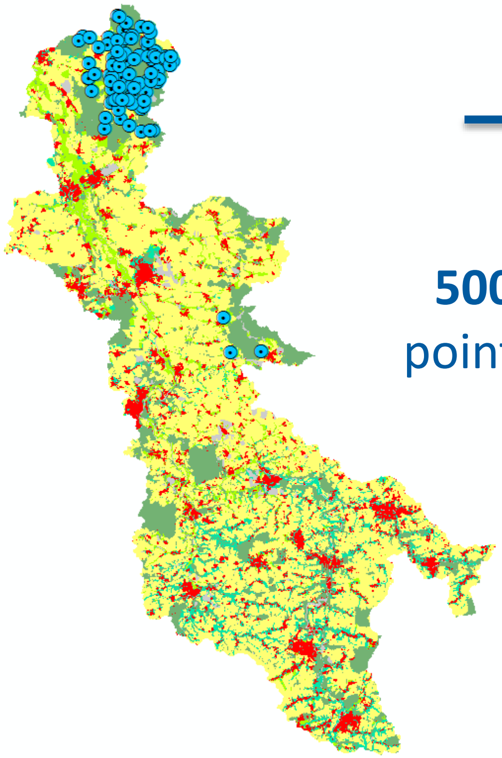
- Next stream
- Next road

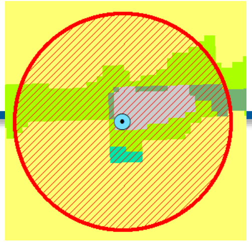
Climate

- Temperature
- Temperature ranges
- Precipitation

Presence and absence

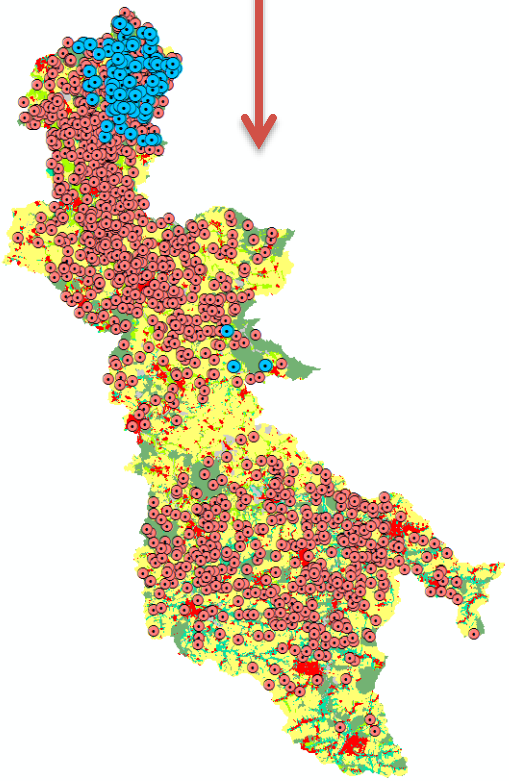
Presence data points available for each species:





500 m buffer around each data point to avoid overlay of predictor variables

Data points for other species outside the buffer **considered as Pseudo-absence**:



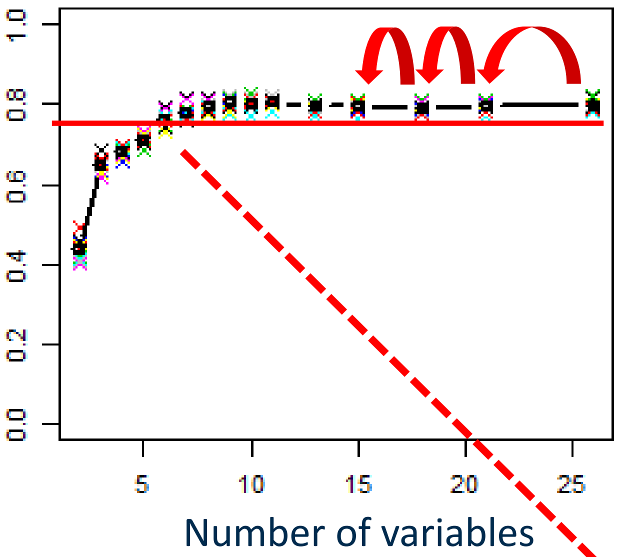
Annex

Variable selection

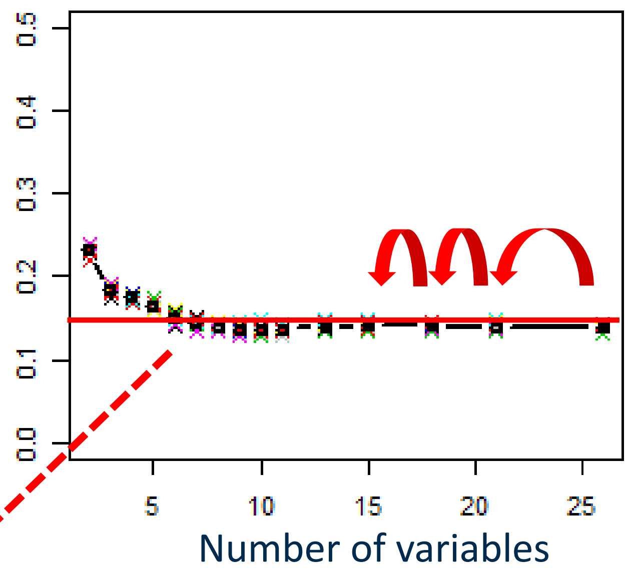
(Kiebitz)

-> Reduction of the 26 variables using:

pseudo-R^2



RMSE



Selected variables

(for each species ten repetitions)

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Variable selection

(Kiebitz)

Land use

(within a radius of 250 m)

- ~~Urban~~
- ~~Transportation~~
- Cropland
- Pasture (total, ~~extensive, intensive~~)
- Forest (total, ~~deciduous, coniferous, mixed~~)
- ~~Horticulture~~
- Wetlands (species-specific need)
- ~~Water~~
- ~~Barren~~

Soil

- Available water capacity
- ~~Bulk density~~
- Carbon content
- ~~Satur. hydraulic conductivity~~

Linear elements

- ~~Share on HRU area~~
- Share on HRU perimeter
- ~~Forest edges~~

Distance parameters

Distance to:

- Next stream
- Next road

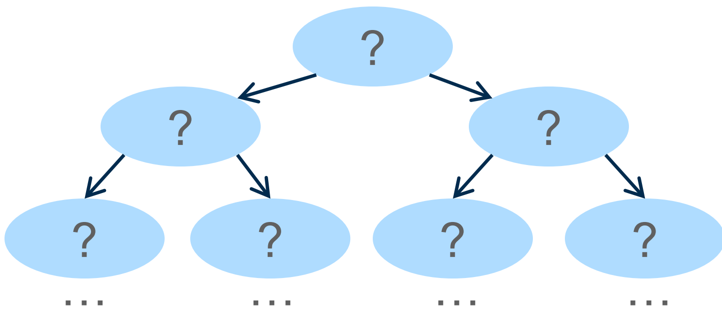
Climate

- Temperature
- Temperature ranges
- Precipitation

Modeling

Modeling with decision trees (Random Forest)

Random generation of a **decision tree** based on the data:



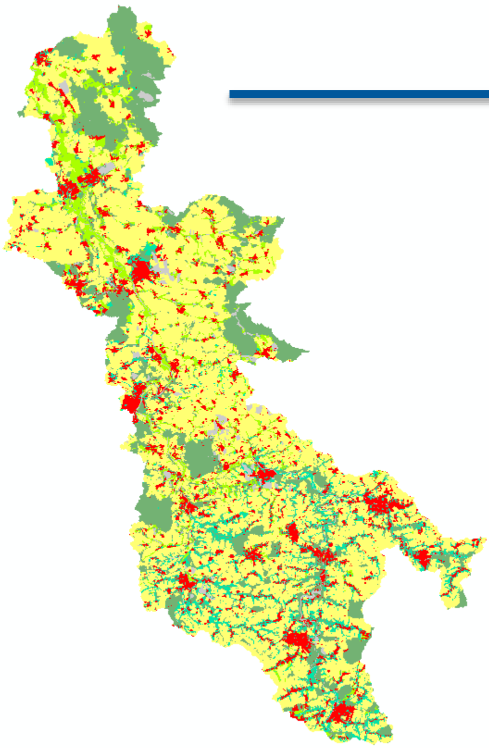
Repeated 500x

(for each species ten repetitions)

Model

= „Forest“

Prediction of breeding habitat



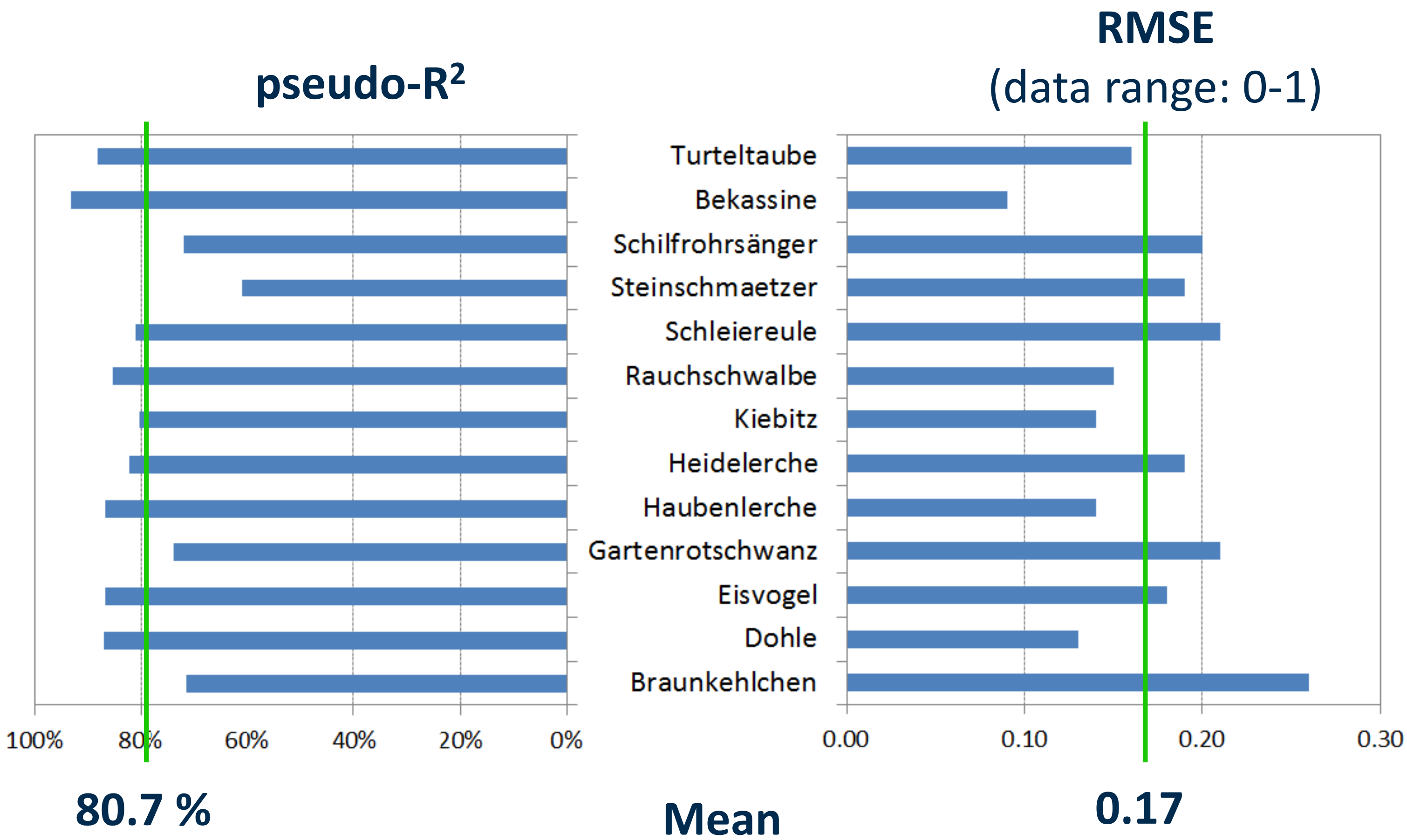
Land use scenario

Prediction using all ten models per species

Presence/absence is a majority decision

UFZ

Model performance



The tool

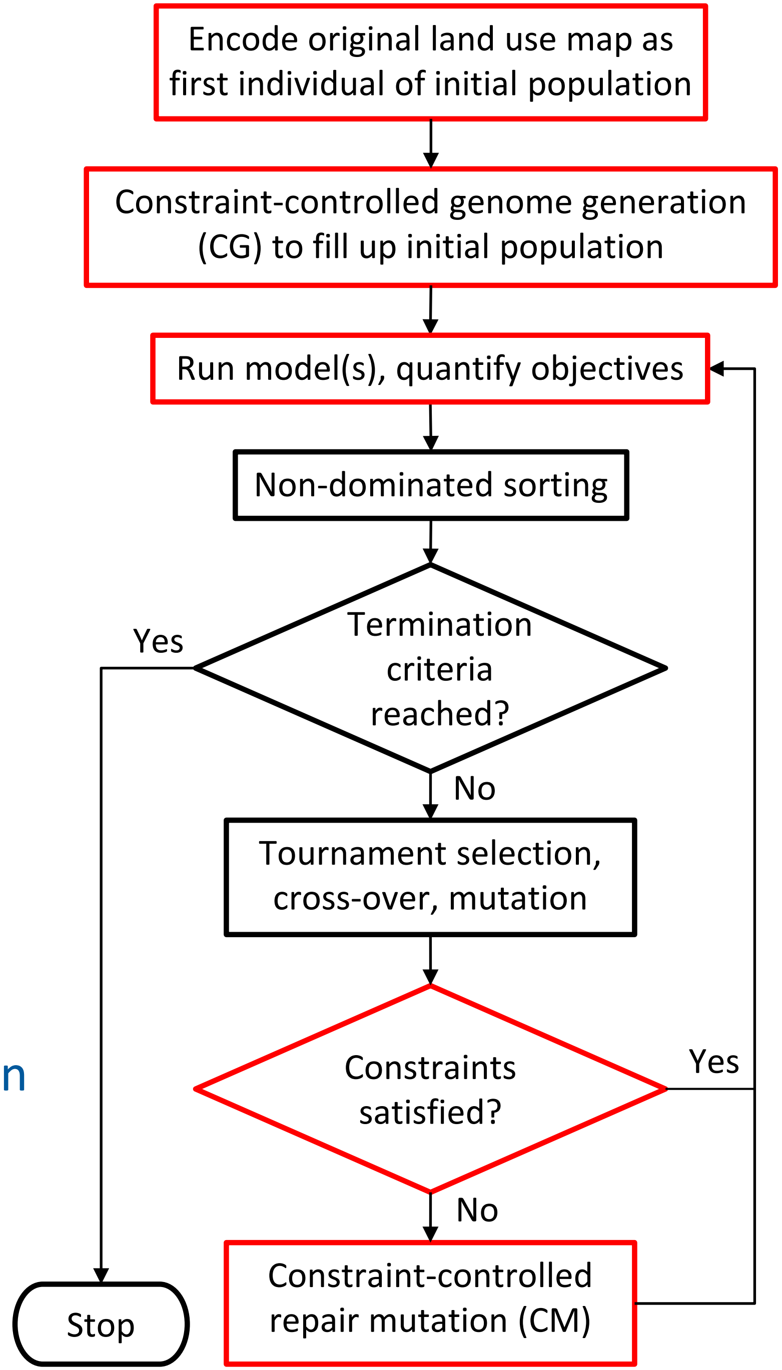
CoMOLA

Constrained
Multi-objective
Optimization of
Land use
Allocation

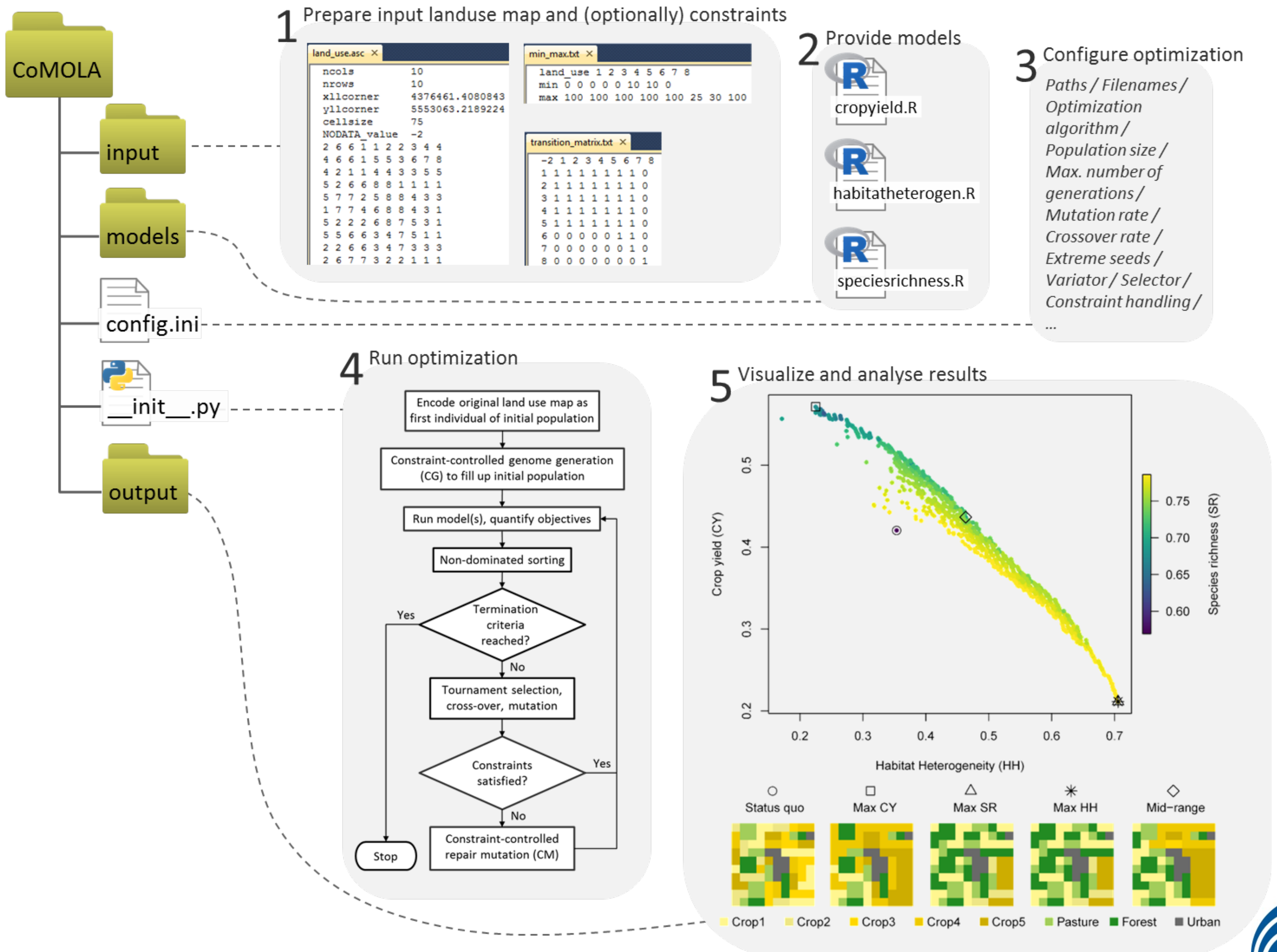
NSGA-II and **GA** algorithms from *inspyred* Python package enhanced for land use optimization (maps, models, constraints)

Constraint handling methods:

- Constraint-controlled genome generation & repair mutation (CG-CM)
- Constraint Tournament Selection (CTS)



Annex



https://github.com/michstrauch/CoMOLA