Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Automatic selection of contiguous forest reserves

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Master Thesis of Sabrina Maurer

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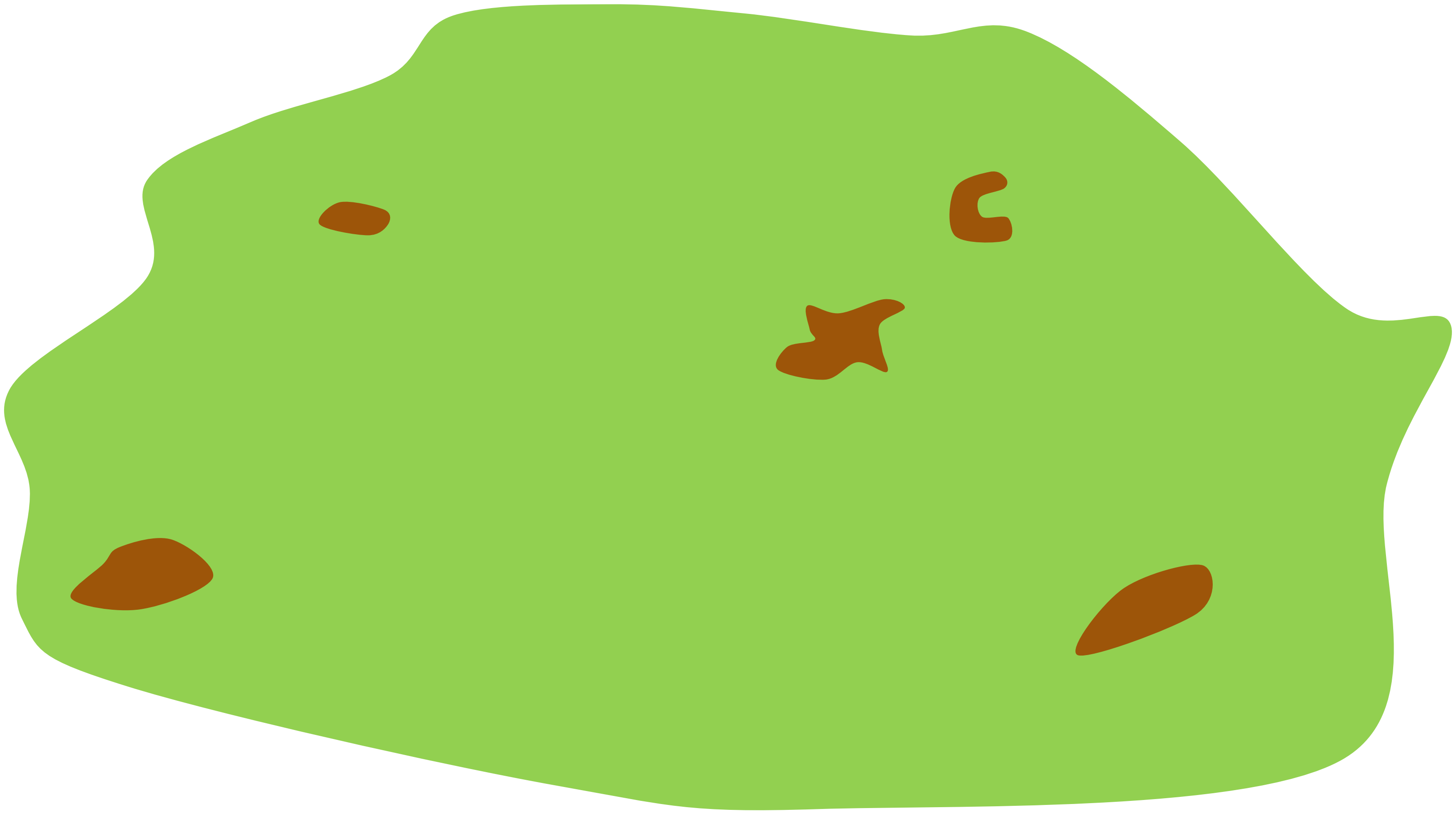
Problem – selection of reserves



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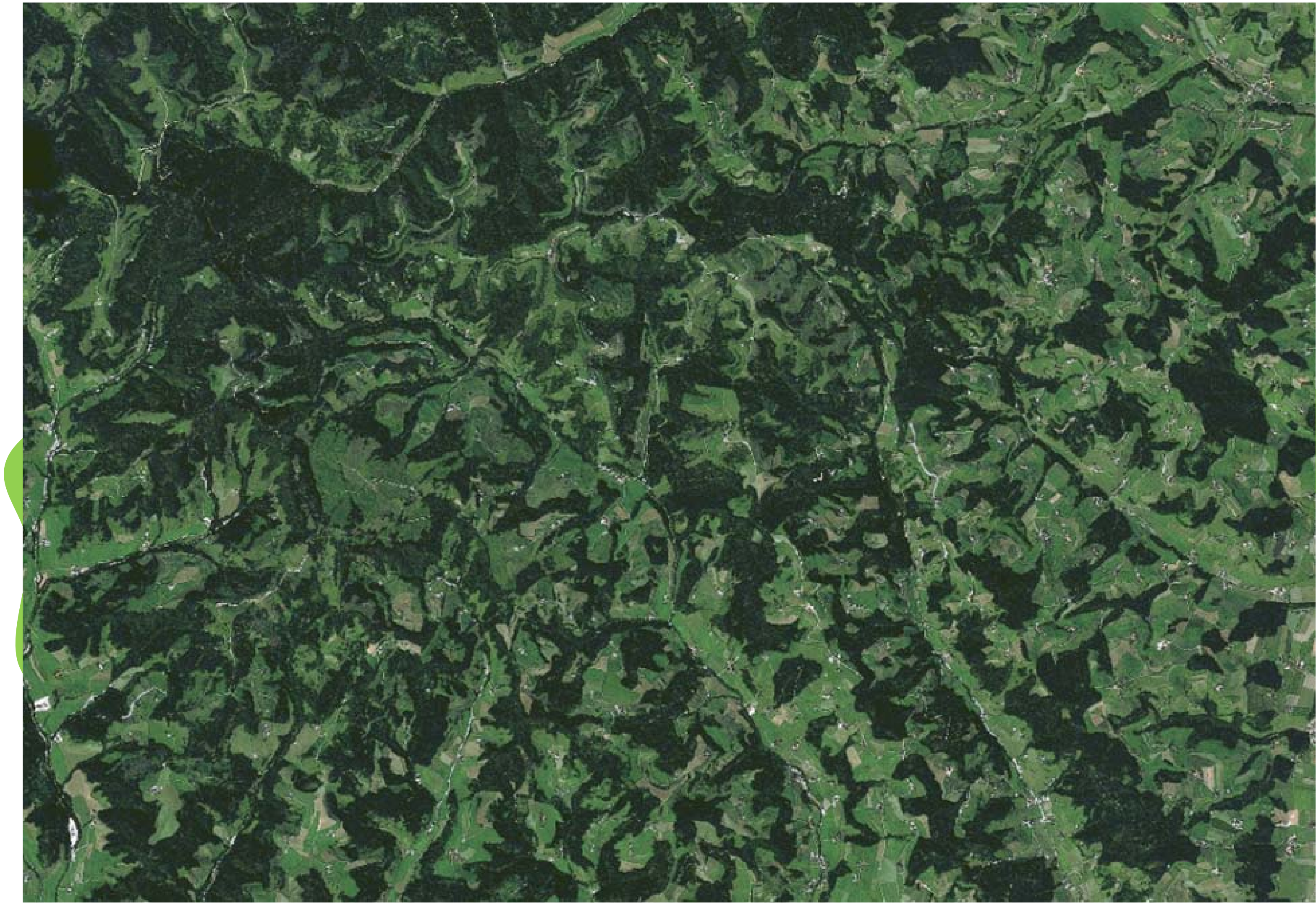
Problem – real world situation



Aim of the thesis

Develop a general model for an automatic selection of contiguous forest reserves considering ecological and economical aspects

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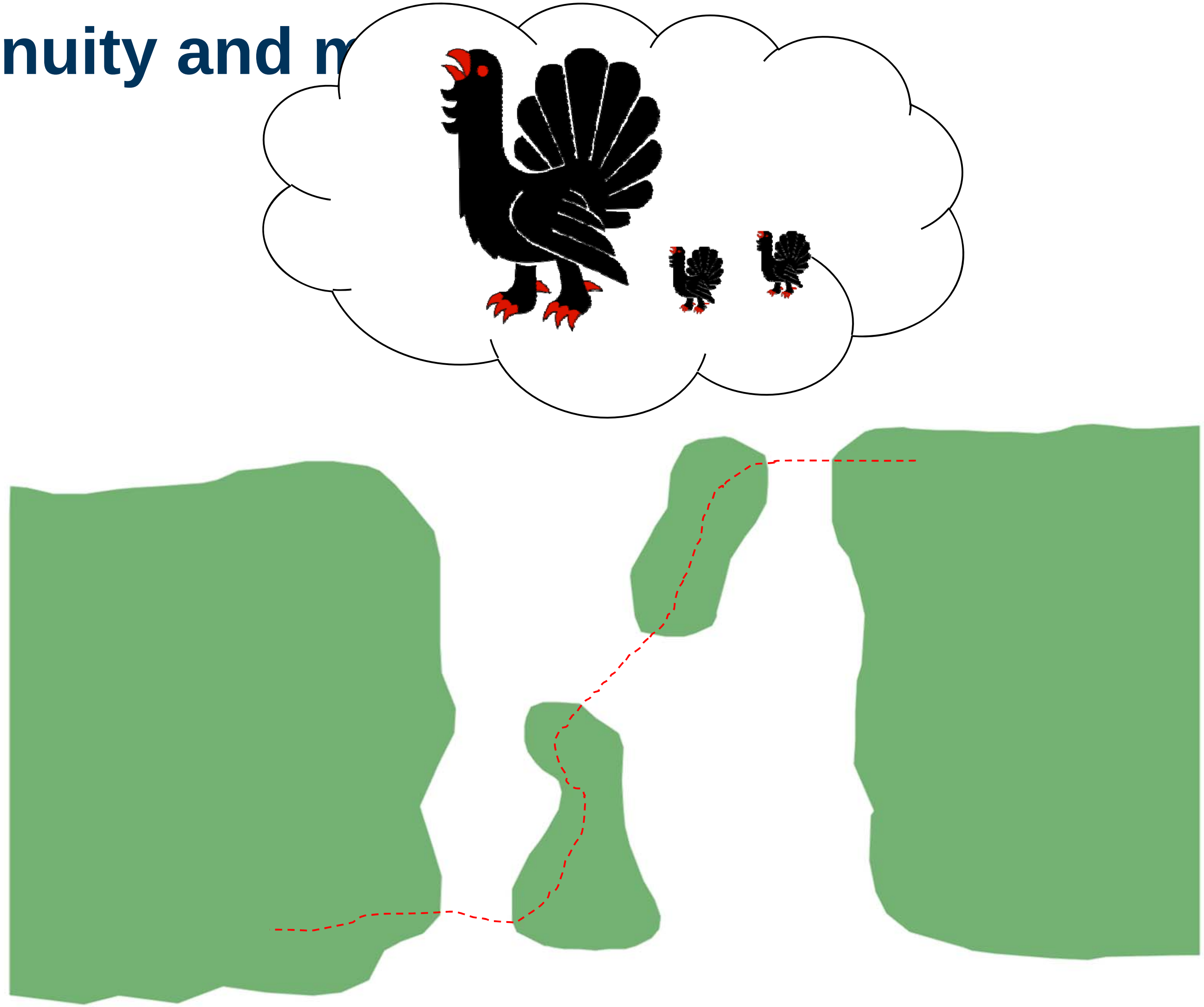
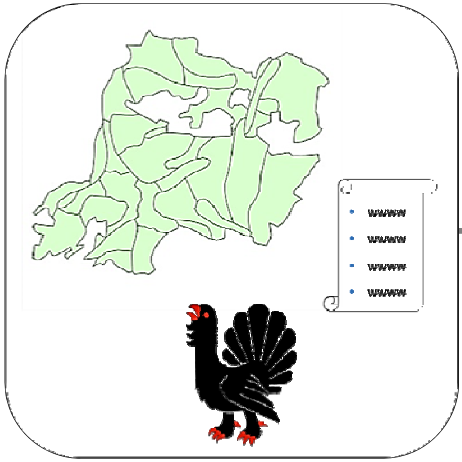
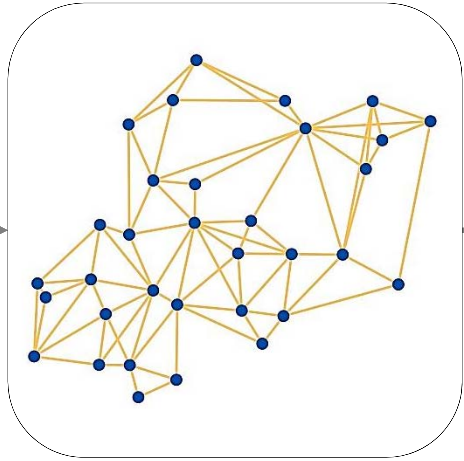
Continuity and m

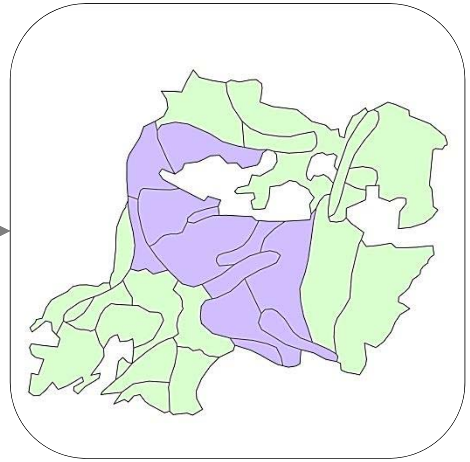




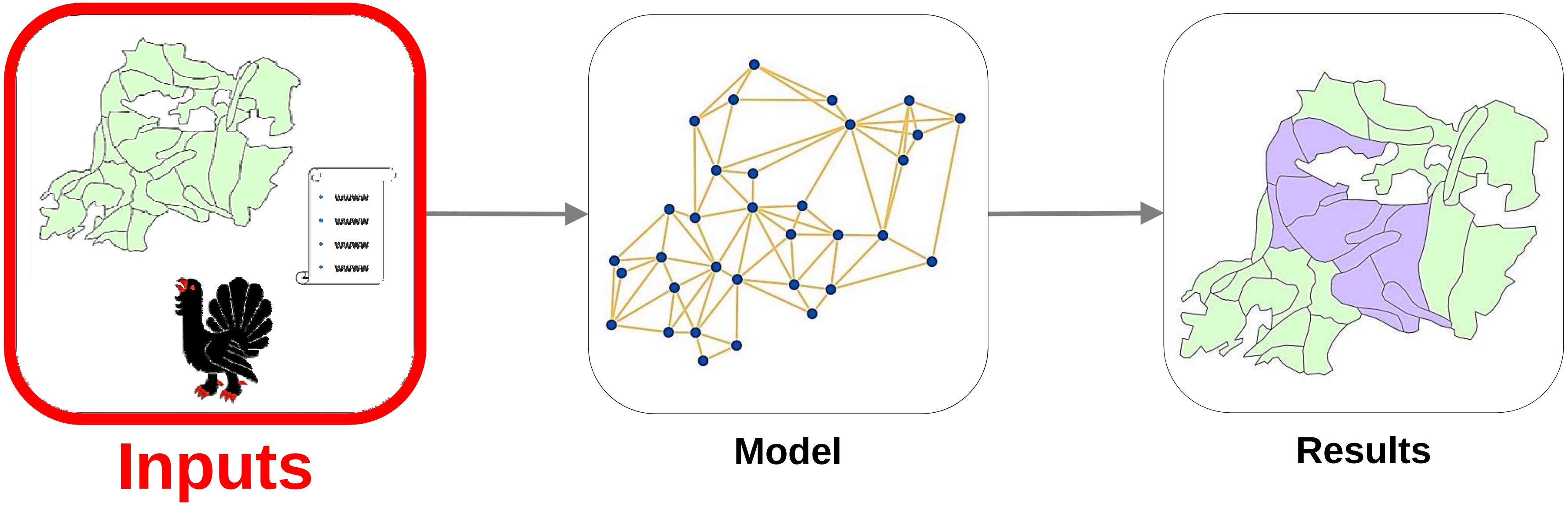
Inputs



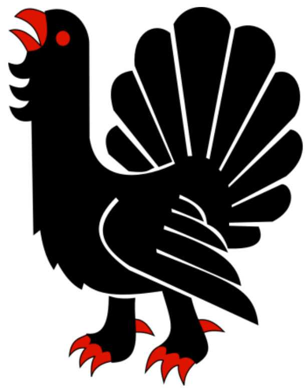
Model



Results


Inputs
Model
Results

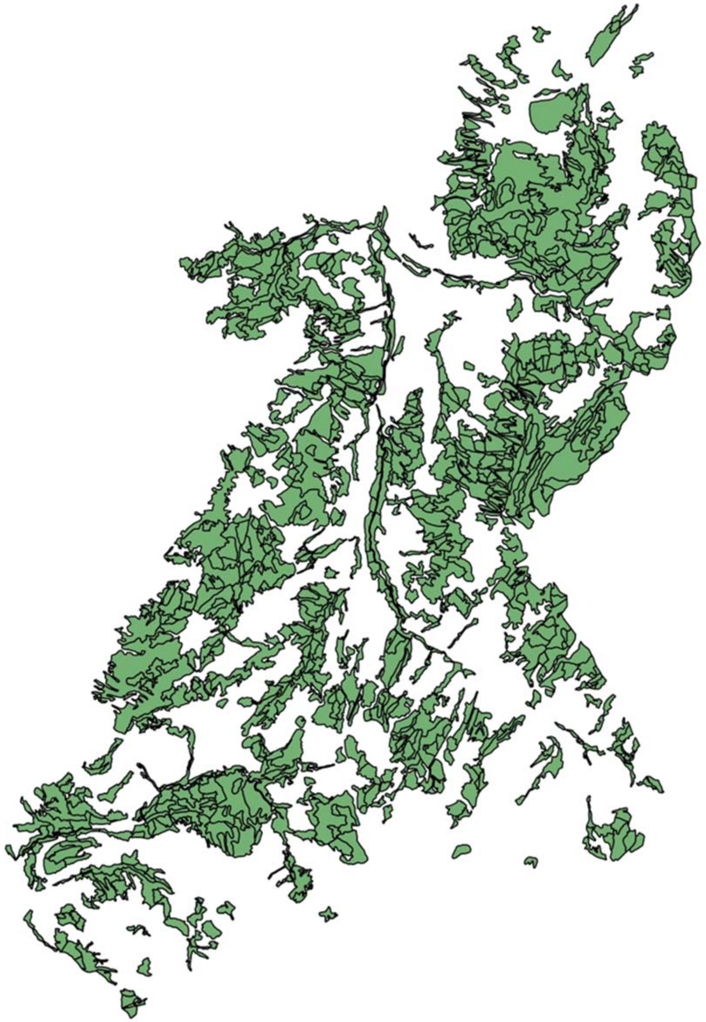
Inputs



- **Conservation aim**
- Decision units
- Constraints
- Assessment criteria incl. weighting

Input

- Conservation aim
- **Decision units**
- Constraints
- Assessment criteria incl. weighting



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Input

- Conservation aim
- Decision units
- **Constraints**
- Assessment criteria incl. weighting

Input

- Conservation aim
- Decision units
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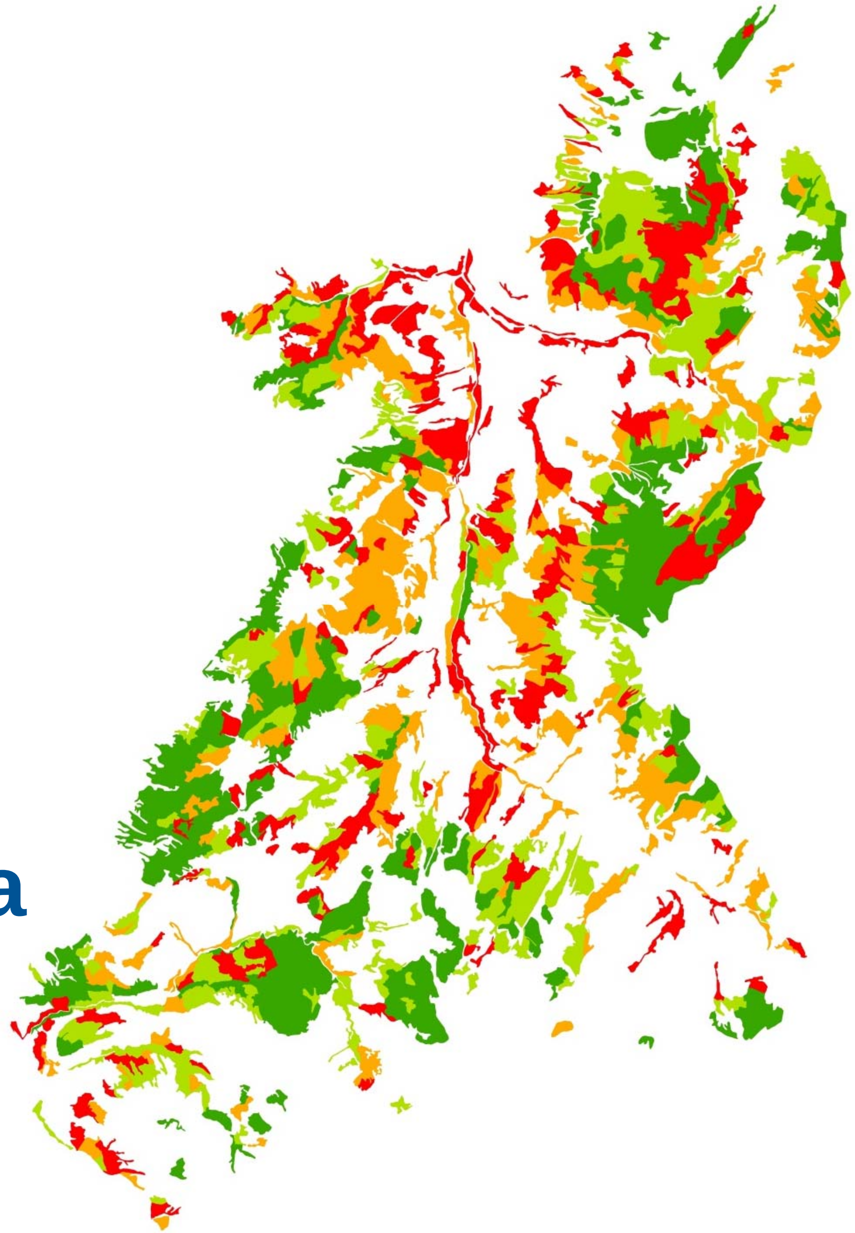
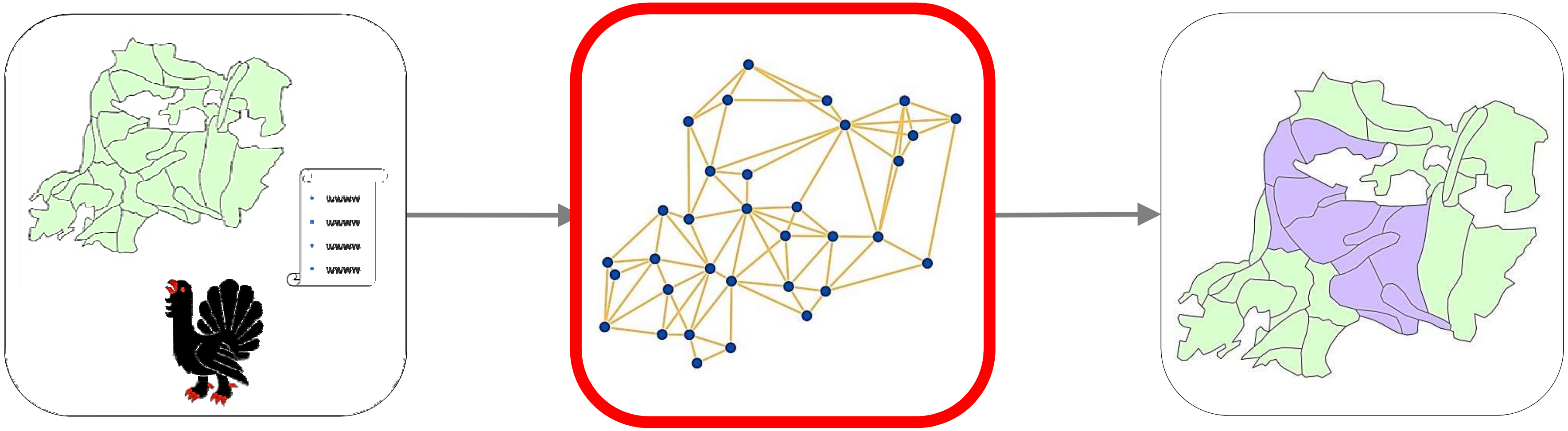
- **Assessment criteria incl. weighting**





Inputs **Model** **Results**

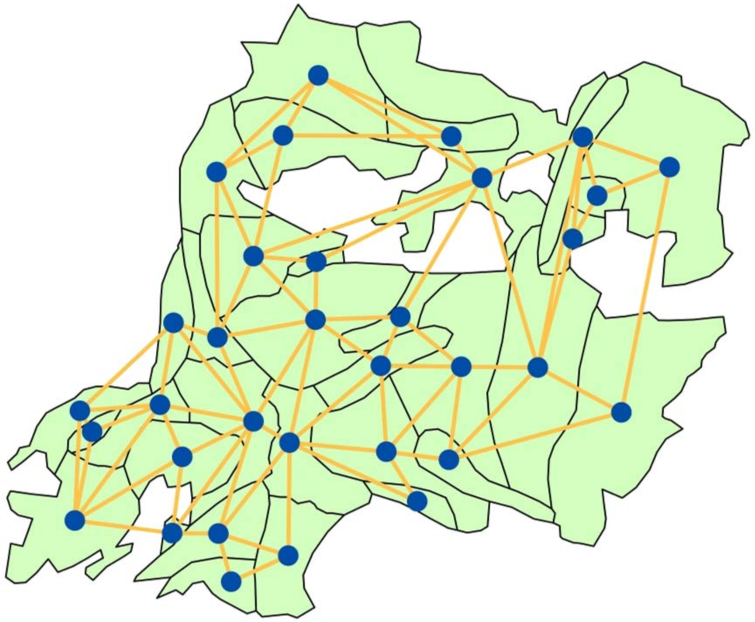
Optimization

Integer Linear Programming (ILP)

Objective: Maximize the suitability of the selected patches

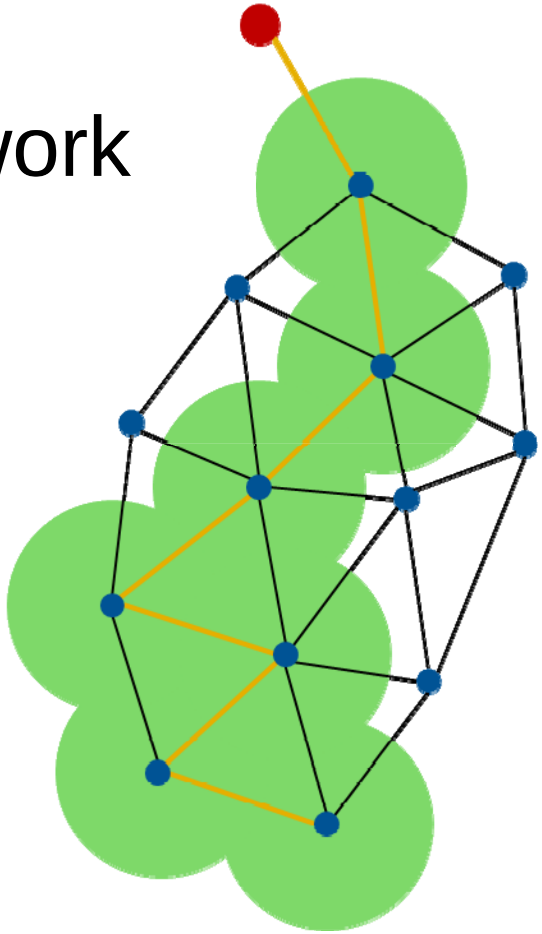
Constraints:

- Maximum area
- Number of regions
- Contiguity



ILP

- Forest represented as a network
- Add exit node
- Search a path from start node to exit node



Model parameters

letter	description
x_i	1 if patch i is selected, 0 otherwise
y_{i0}	1 if edge between patch i and exit node is selected, 0 otherwise
y_{ij}	1 if edge between patch i and j is selected, 0 otherwise
y_{ji}	1 if edge between patch j and i is selected, 0 otherwise
h_i	Suitability of patch i
B	Maximum area
c_i	Area of patch i
R	Maximum quantity of regions
I	set of patches i
N	Number of patches
N_i	Set of adjacent patches j of patch i
G	Set of patches i of the cycle (=potential start node)

Analytical Model (ILP)

Objective Function

$$Max \sum_{i=1}^{N} \sum_{j \in N_i} y_{ji} * h_i$$

Maximize suitability

s.t.

$$\sum_{i=1}^{N} x_i * c_i \leq B$$

Maximum area

$$\sum_{i=1}^{N} y_{i0} \leq R$$

Number of regions

$$\sum_{j \in N_i} y_{ij} \geq x_i,$$

for all i ∊ I

$$y_{ji} \leq \sum_{j \in N_i} y_{ij}$$

for all i ∊ I

$$y_{ij} \leq x_i,$$

for all i ∊ I

$$y_{ij} + y_{ji} \leq 1$$

Continuous flow

$$x_i \in \{0,1\}, y_{ij} \in \{0,1\}$$

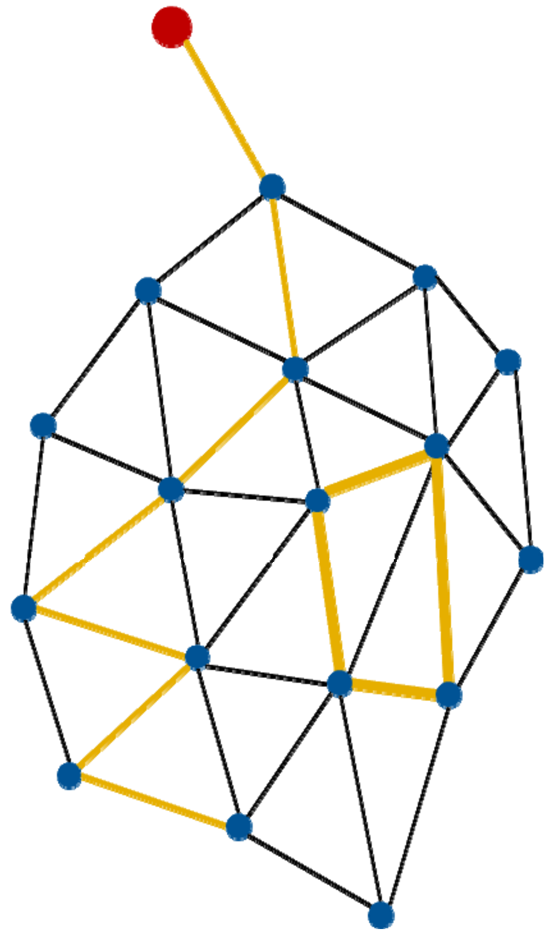
Binarity

Cycle prohibiting constraints

Solutions with several cycles

Introduce new constraints which prohibit cycles

(from Church and Cova, 2000)



Cycle prohibiting constraints

u is the equivalent of y in the cycle

w_i: 1 if node i is the start node of the cycle, 0 otherwise

e: 1 if a cycle exists, 0 otherwise

$$x_i \leq e, \qquad \text{for all } i \in G$$

$$e \leq \sum_{i \in G} w_i$$

$$w_i + \sum_{j \in N_i} u_{ji} = \sum_{j \in N_i} u_{ij}, \qquad \text{for all } i \in G$$

$$\sum_{j \in N_i} u_{ji} = \sum_{j \in N_i} u_{ij}, \qquad \text{for all } i \notin G$$

$$e = \sum_{i=1}^{N} u_{i0}$$

$$u_{ij} \leq y_{ij}, \qquad \text{for all } i \in I$$

$$e \in \{0,1\}, \qquad u_{ij} \in \{0,1\}, \qquad w_i \in \{0,1\}$$

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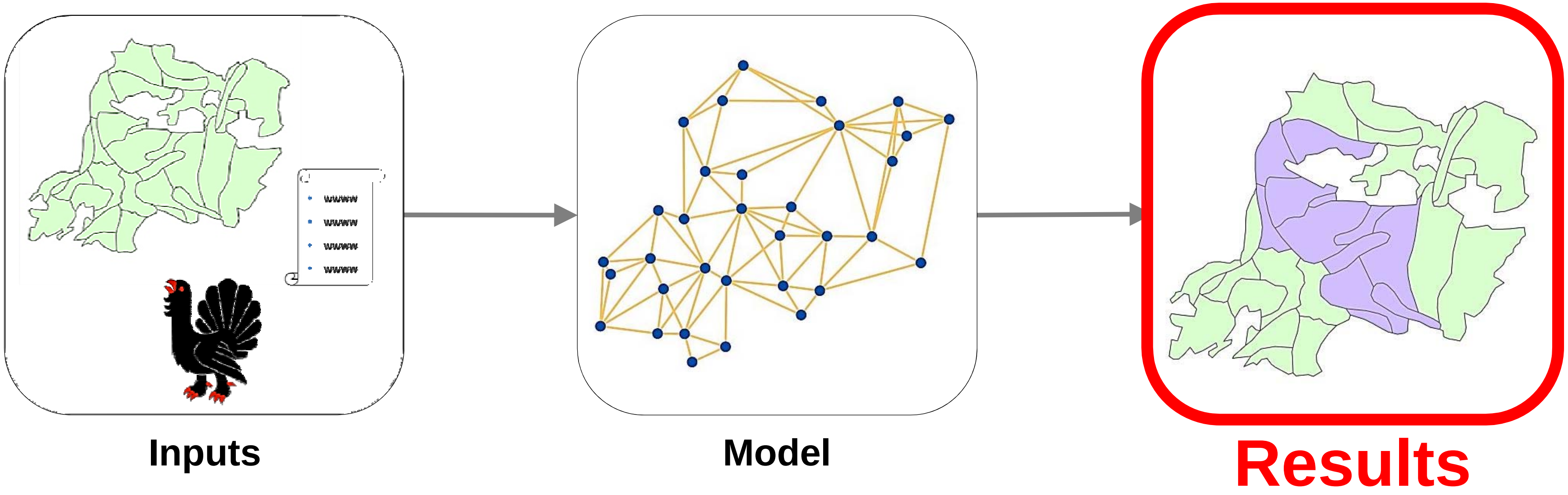
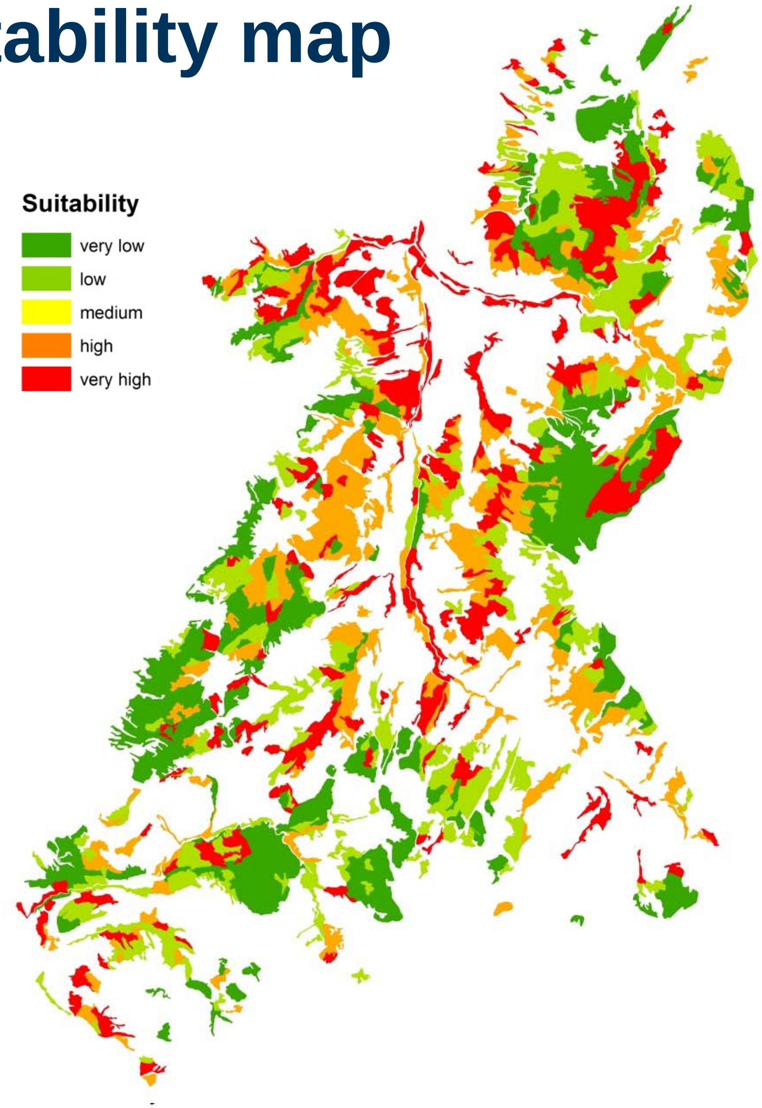
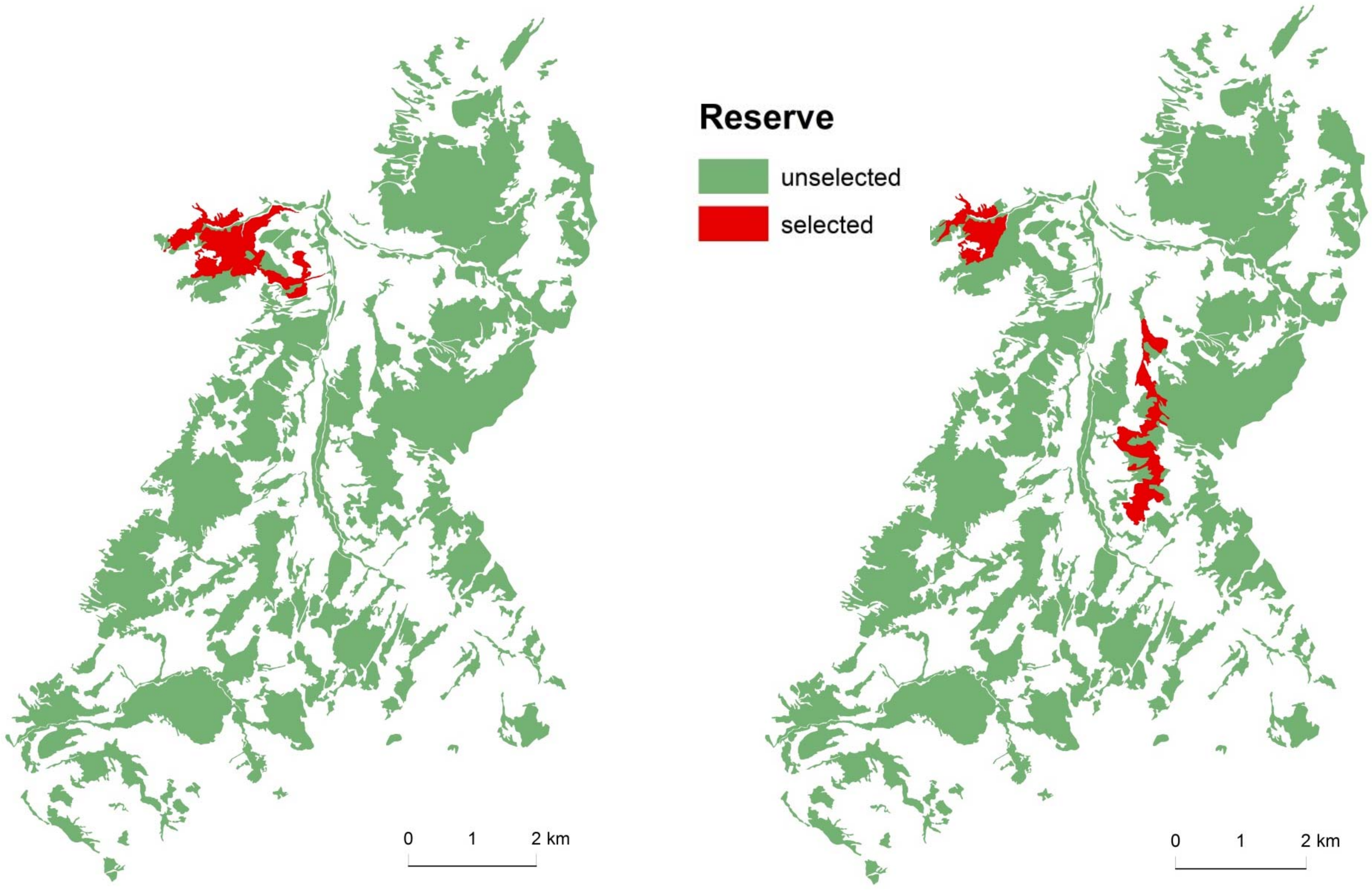


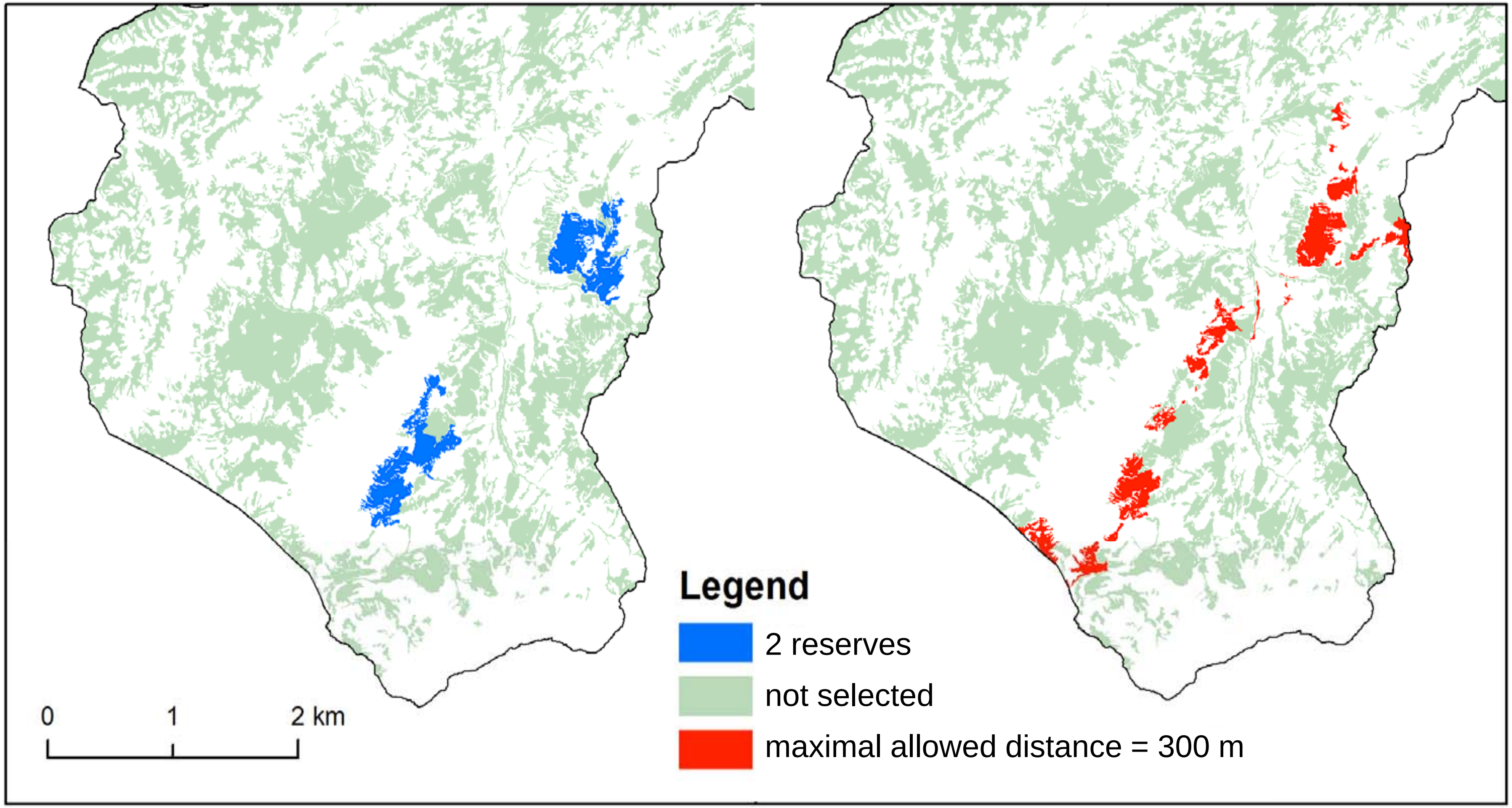
Results – Suitability map



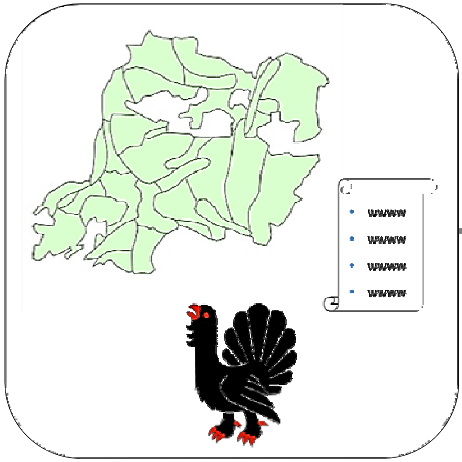
Results – 1 region vs. 2 regions



Results – stepping stones

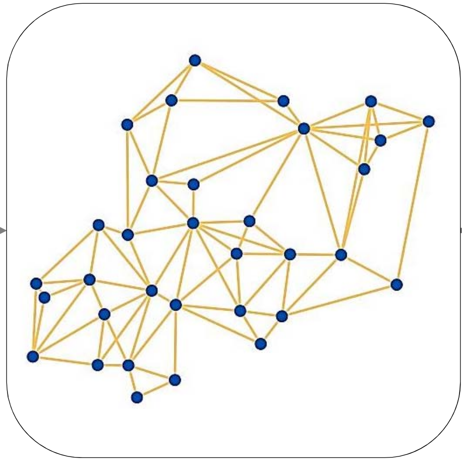


Summary



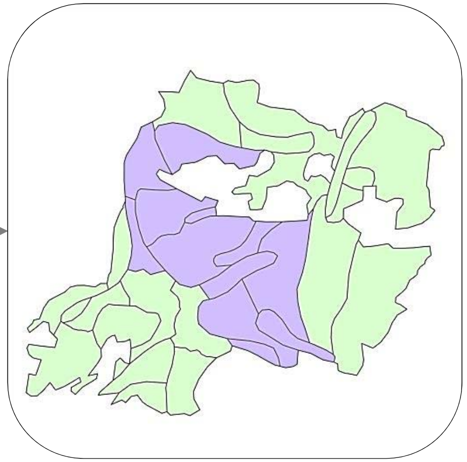
potential reserve sites + assessment criterias

represent forest as a network



accept separated patches within a certain distance as adjacent

find optimal solution



suggested reserve

Outlook

Improvement

- Include barriers
- Other patch shapes
- Better geodata
- More computing power

Need for research

- Better knowledge about behaviour and needs of species
- Faster mathematical models to ensure contiguity


Thanks a lot for your attention!

ILP formula part 1

Maximize the suitability

$$Max \sum_{i=1}^{N} \sum_{j \in N_i} y_{ji} * h_i$$

Budget constraint or maximum selected area must be adhered to:

$$\sum_{i=1}^{N} x_i * c_i \leq B$$

If patch i is selected, at least one link must lead away from it:

$$\sum_{j \in N_i} y_{ij} \geq x_i, \qquad \text{for all } i \in I$$

If a link leads to patch i, at least one link must lead away from it:

$$y_{ji} \leq \sum_{j \in N_i} y_{ij} \qquad \text{for all } i \in I$$

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ILP formula part 2

The number of links to the exit node, has to be less or equal than the allowed number of regions:

$$\sum_{i=1}^{N} y_{i0} \leq R$$

If a link leads to patch i, it must be selected:

$$y_{ij} \leq x_i, \qquad \text{for all } i \in I$$

One link can only lead in one direction:

$$y_{ij} + y_{ji} \leq 1$$

The decision variables must be 0 or 1:

$$x_i \in \{0,1\}, y_{ij} \in \{0,1\}$$

Cycle prohibiting constraints part 1

If there is a cycle, the contiguity constraints must be activated:

$$x_i \leq e,$$ for all i ∊ G

If the contiguity constraints are active, the flow must start from a node in the cycle:

$$e \leq \sum_{i \in G} w_i$$

Flow balance in the potential start nodes (Input = Output):

$$w_i + \sum_{j \in N_i} u_{ji} = \sum_{j \in N_i} u_{ij},$$ for all i ∊ G

Flow balance in the nodes (except for start nodes):

$$\sum_{j \in N_i} u_{ji} = \sum_{j \in N_i} u_{ij},$$ for all i ∉ G

Cycle prohibiting constraints part 2

If the contiguity network is to be activated, one link to the exit node must exist:

$$e = \sum_{i=1}^{N} u_{i0}$$

If the contiguity network is to be activated, a connection to the corresponding problem must exist:

$$u_{ij} \leq y_{ij}, \qquad \text{for all } i \in I$$

The decision variables must be 0 or 1:

$$e \in \{0,1\}, \qquad u_{ij} \in \{0,1\}, \qquad w_i \in \{0,1\}$$