Scaling Connectivity Conservation Planning with Deep Reinforcement Learning

ML4EO 2026

Exeter, UK

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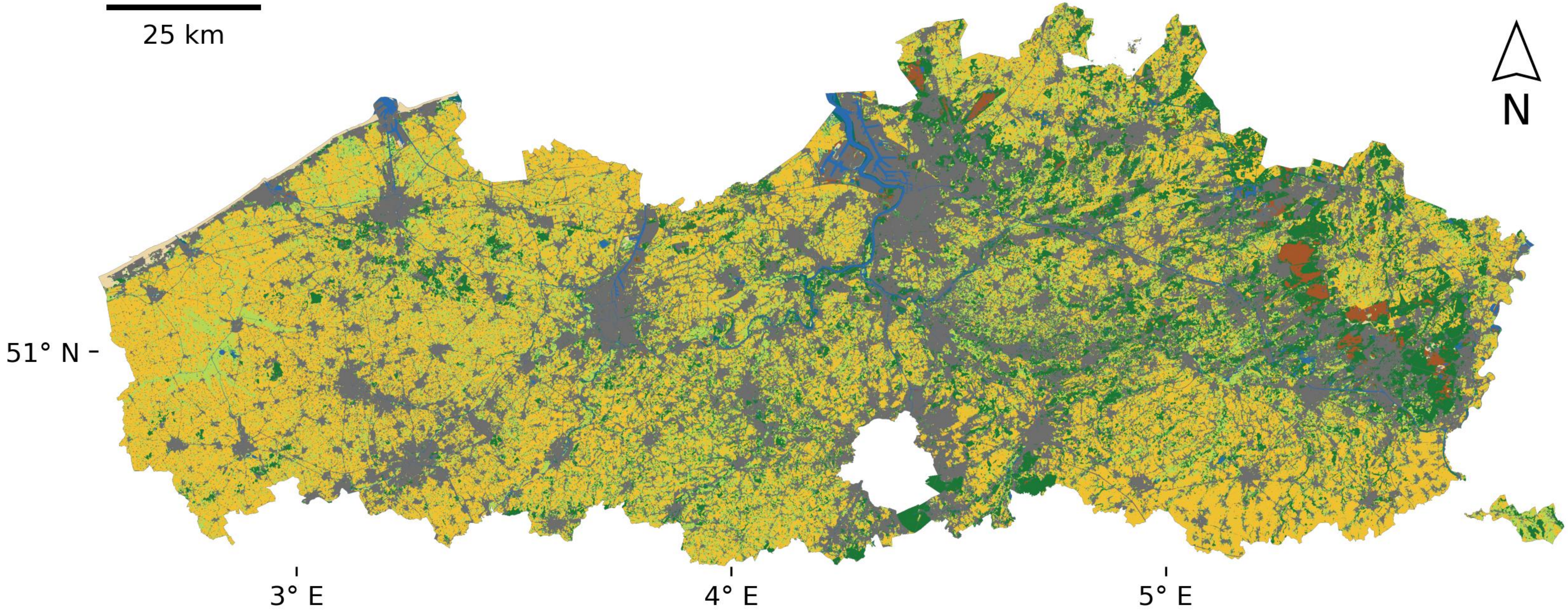
KU LEUVEN

Habitat fragmentation in northern Belgium



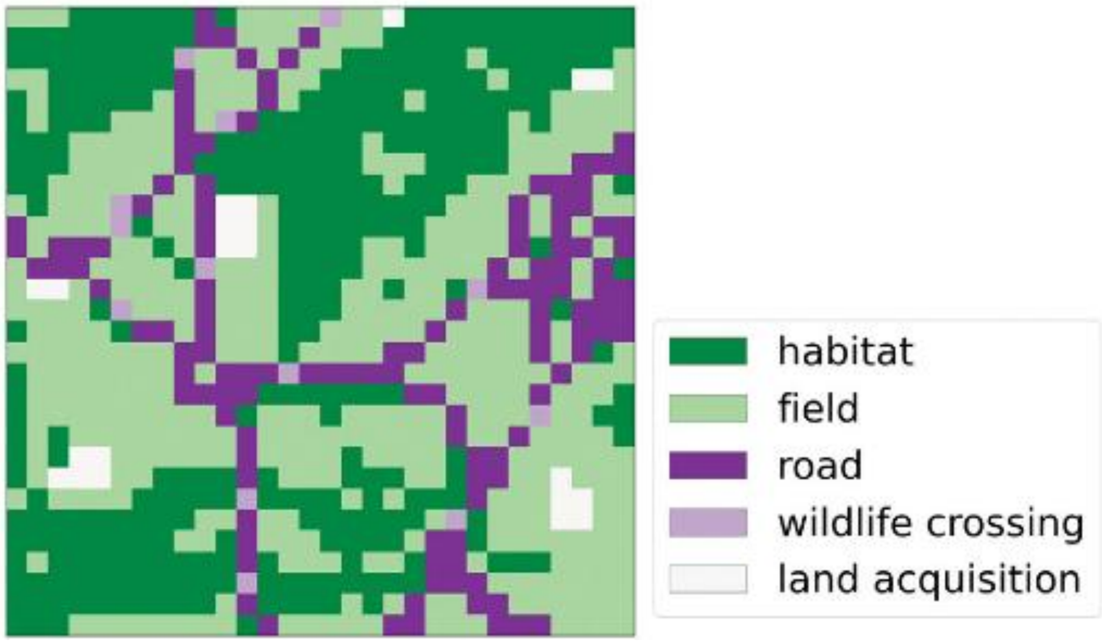
52% agriculture

29% built-up

11% forest

What is connectivity conservation planning?

- Optimize landscape connectivity within budget constraints
- This is a difficult problem
  - If we can only choose between 1000 non-habitat cells and we only need to choose 10 cells → **2.63 x 10^{23} unique solutions**

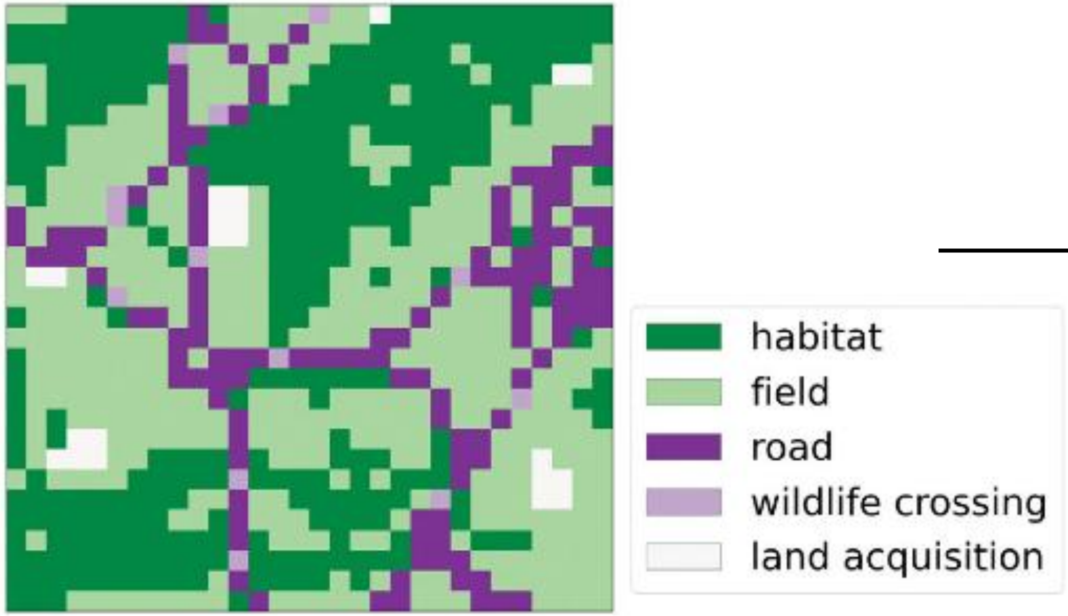


Hamonic et al. 2025

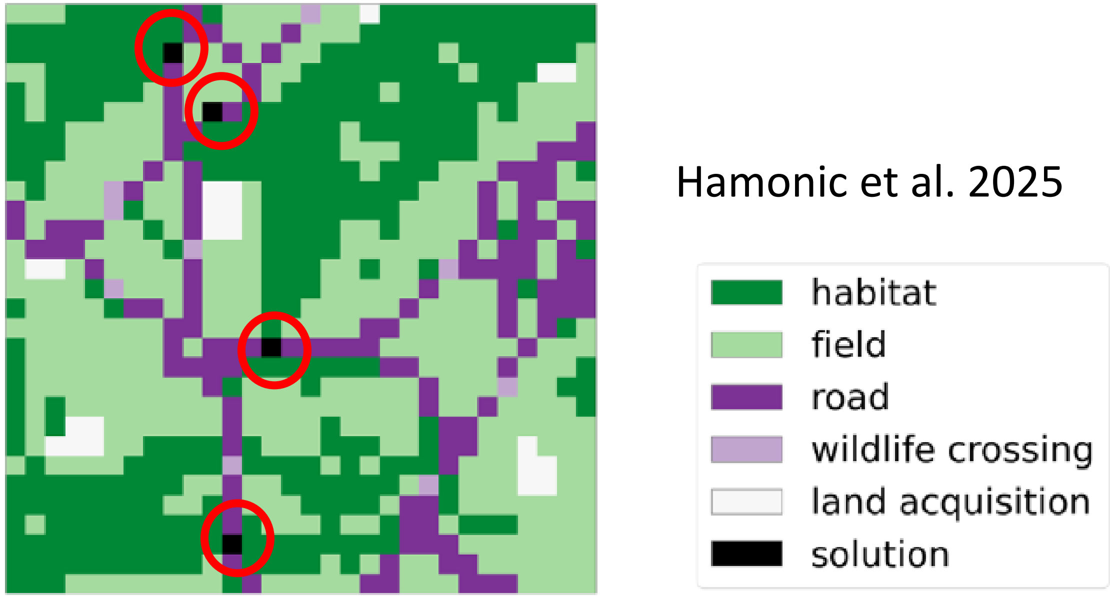
Jim Gade

7.5 x 10^{18} grains of sand on Earth

What is connectivity conservation planning?



30x30 pixels



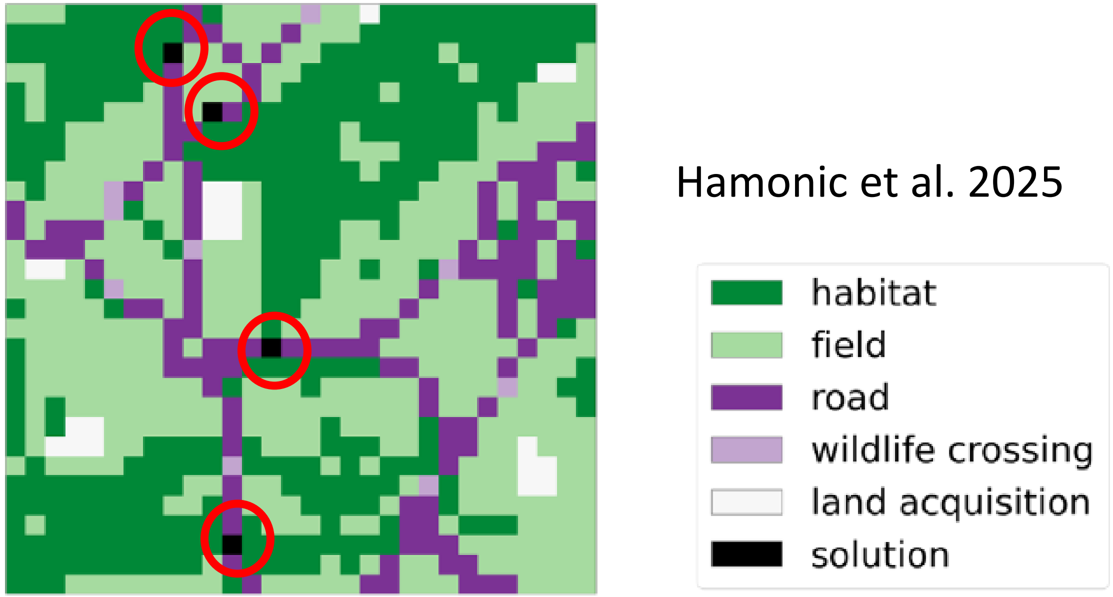
Optimal solution

Hamonic et al. 2025

What is connectivity conservation planning?

✓ Optimality

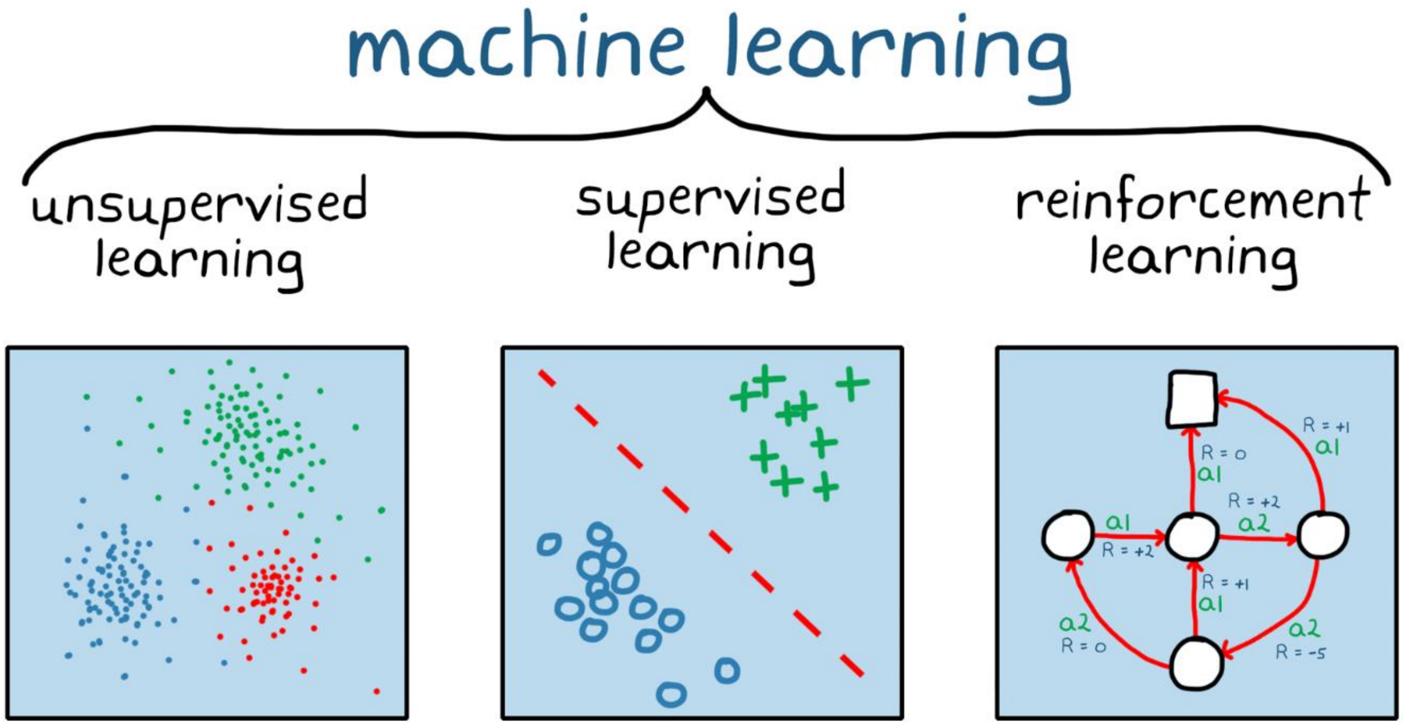
✗ Exponential growth of problem with number of options



Hamonic et al. 2025

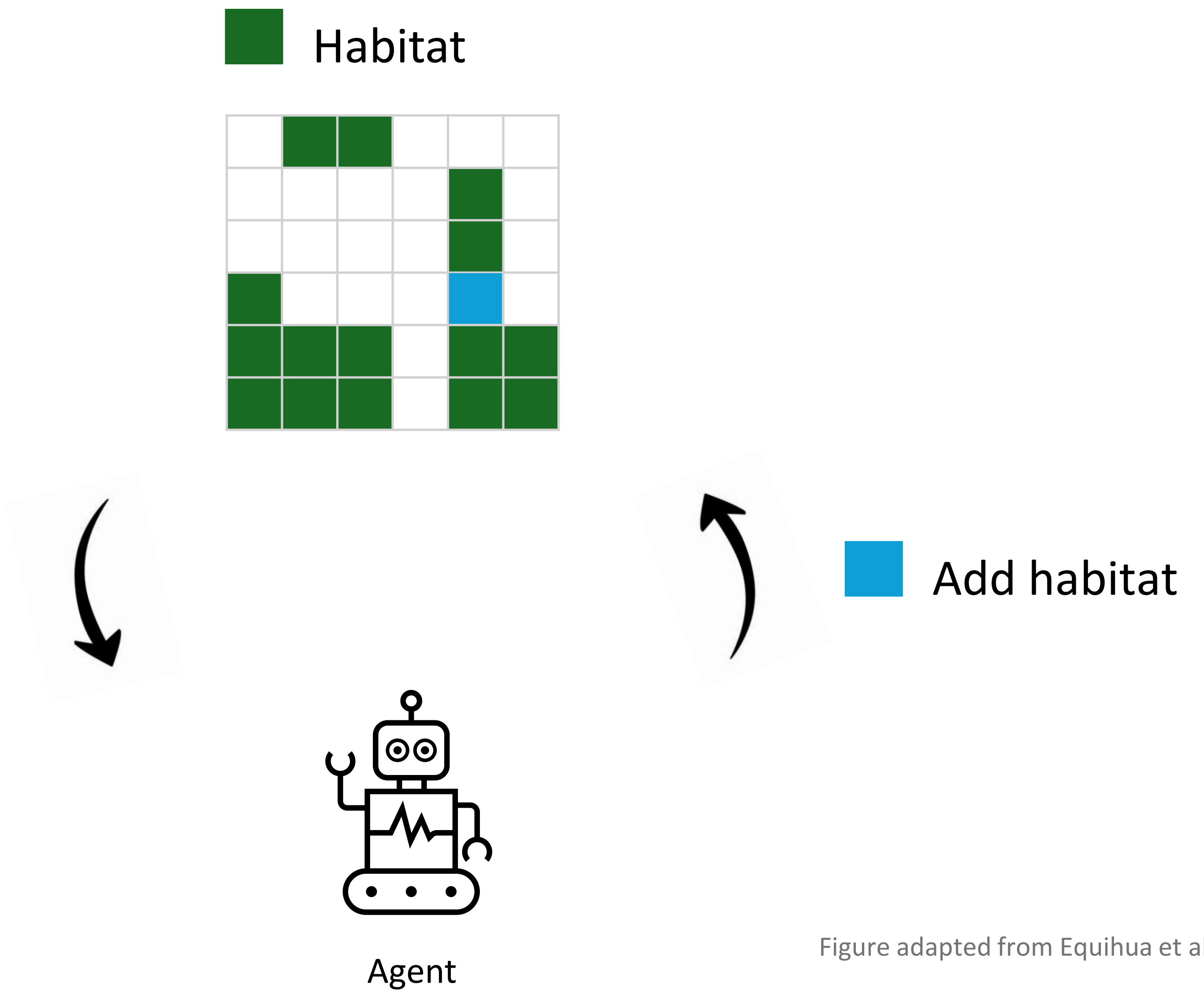
Optimal solution

What is deep reinforcement learning?



Learning by trial and error

How to combine both?



1) Observation of new landscape
2) Reward ★

Connectivity indicator

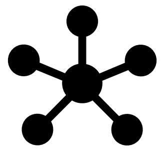
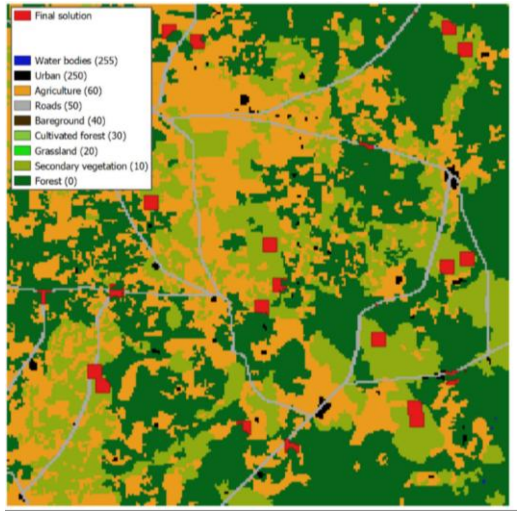


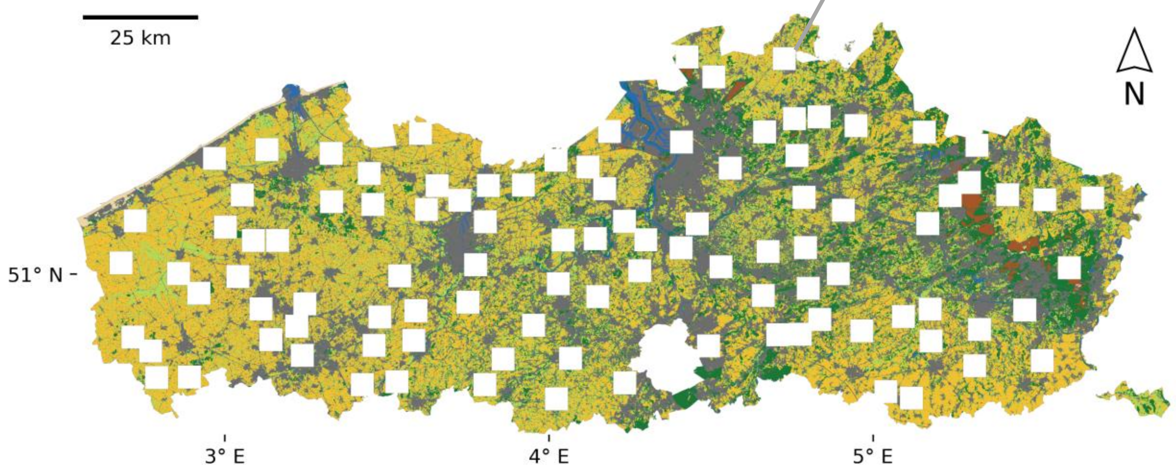
Figure adapted from Equihua et al. (2024)

Creating a generalized model

Validation patches not used for training

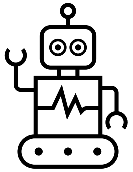


Equihua et al. (2024)



Single patch
250x250

Entire map

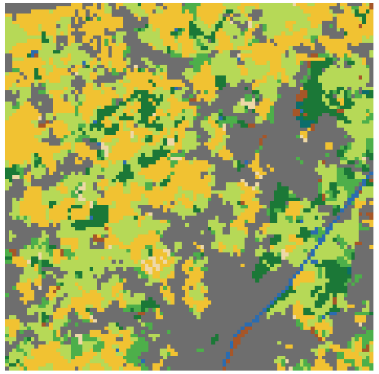


= U-net

Training a generalized model

Step 0

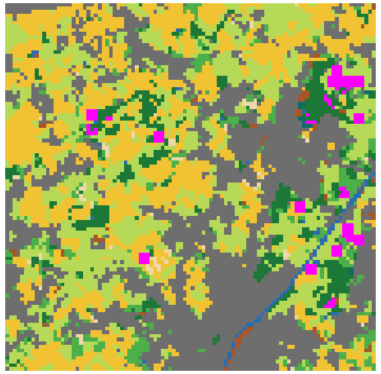
5 km



Budget = 10.000

....

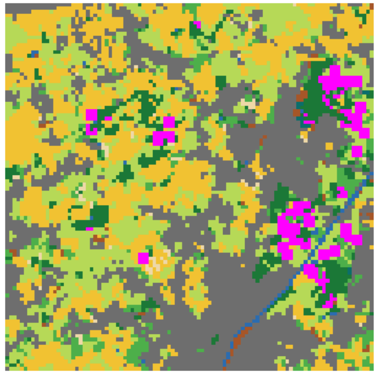
Step 20



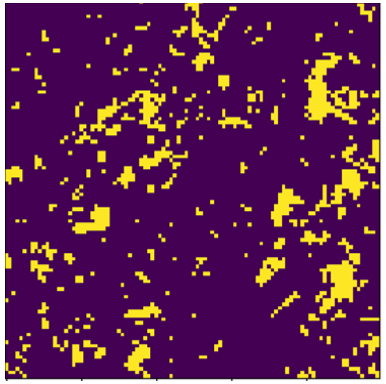
Budget ↓
Connectivity ↑

....

Step 59



Budget = 0
Connectivity ↑↑



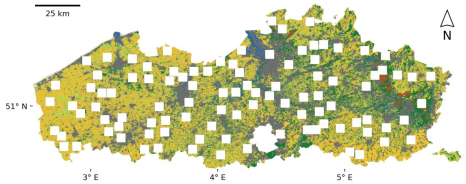
Connectivity

Costs

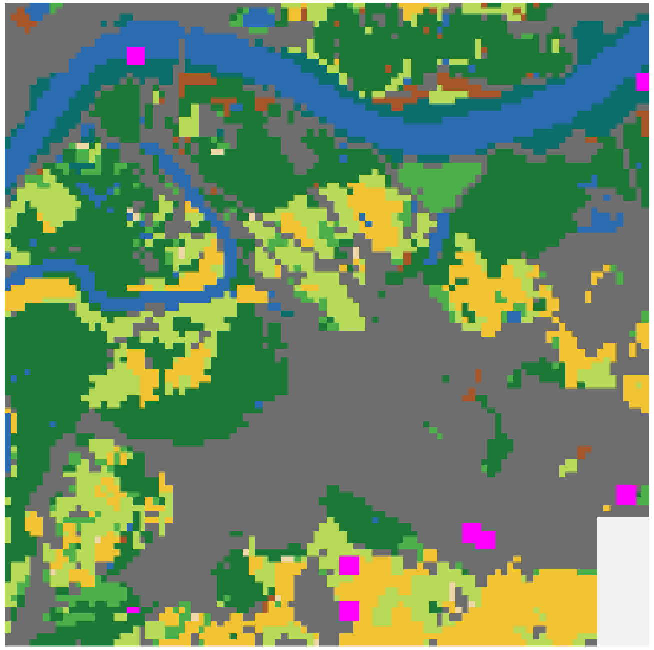
255	Urban
Habitat -> 0	Forest
60	Agricultural field
20	Agricultural grassland
10	Heathland and scrub
40	Dune & fallow
255	Water
40	Swamp
Habitat -> 0	Natural grassland

Does the model generalize?

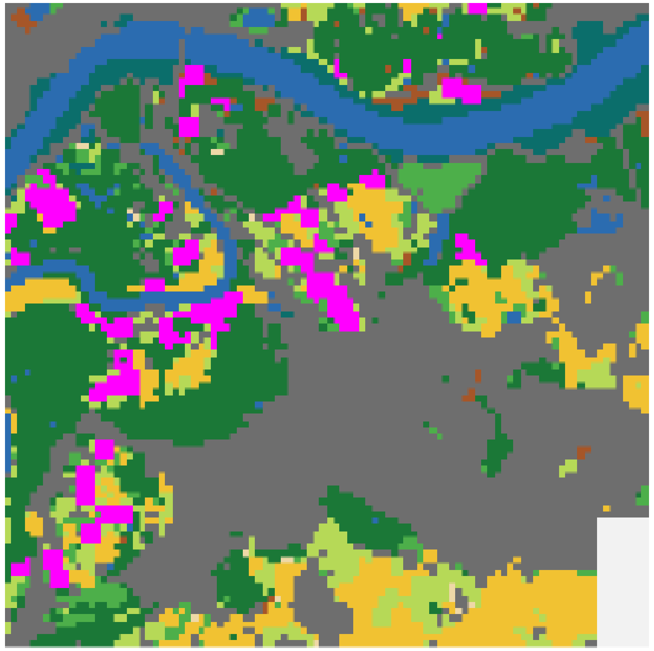
- Yes, model learns to connect habitats!
  - ✗ No optimal solutions
  - ✓ Scalable



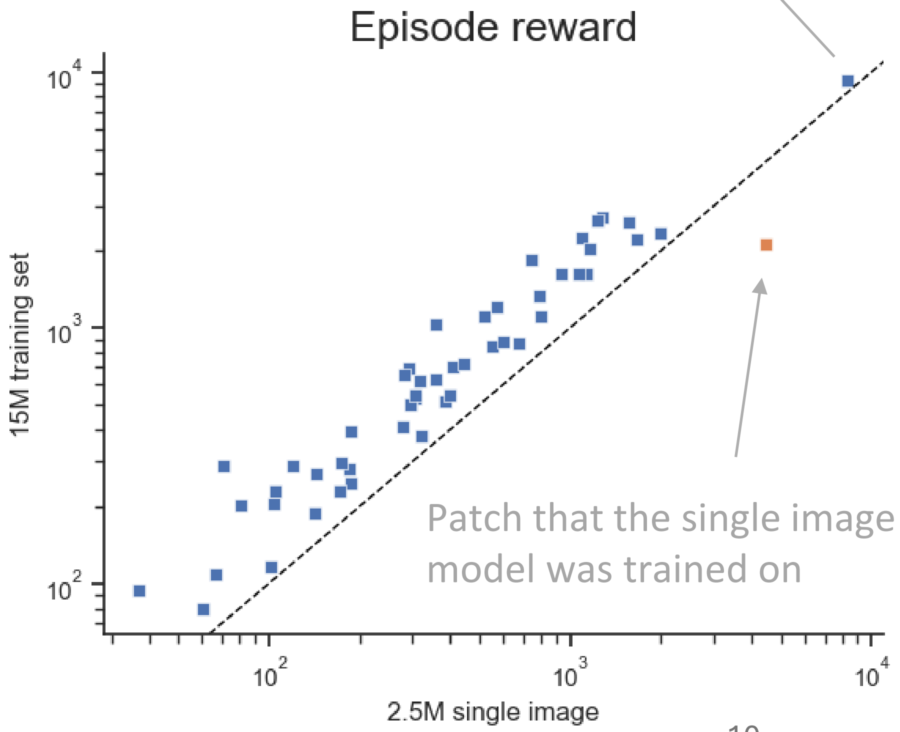
Validation patches



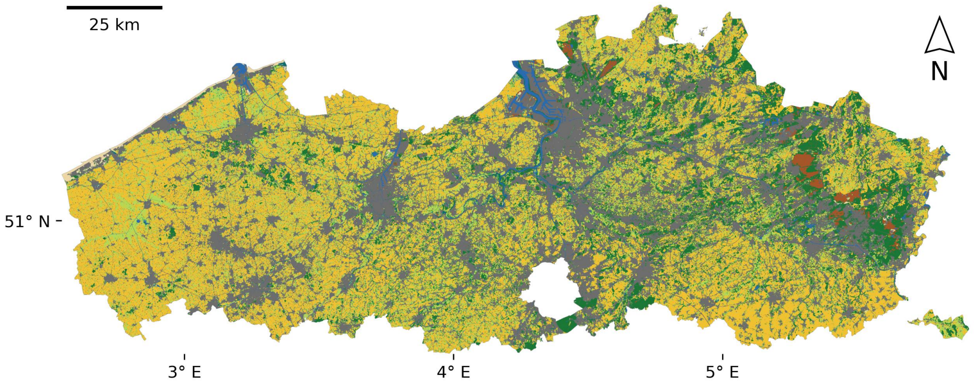
Random agent.



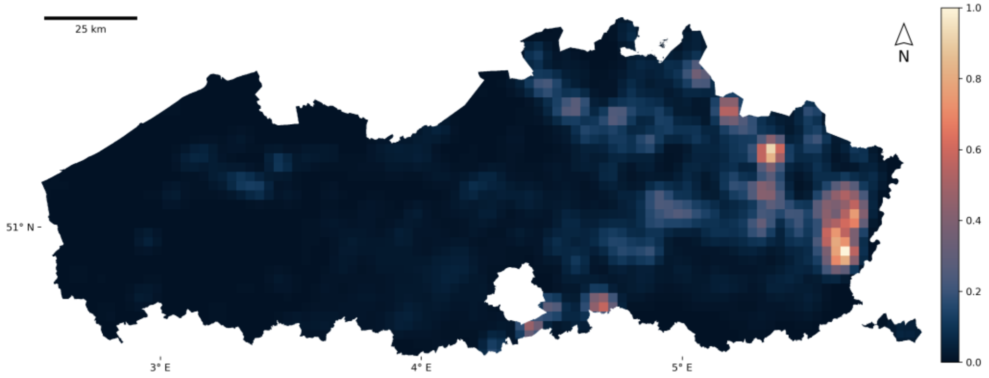
Agent after 15M training steps.



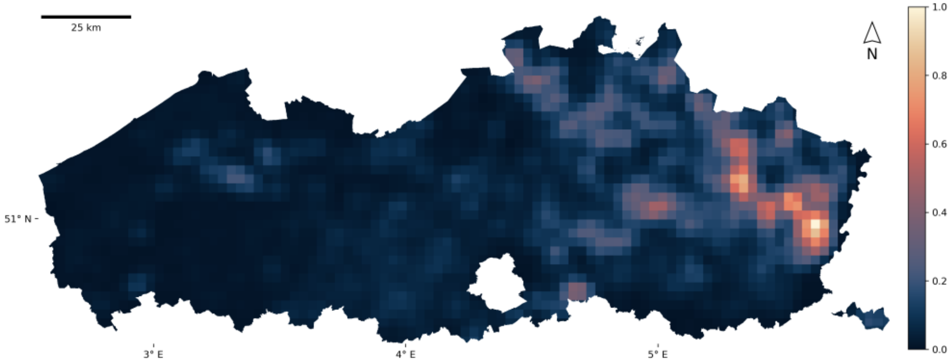
Restoration potential in northern Belgium



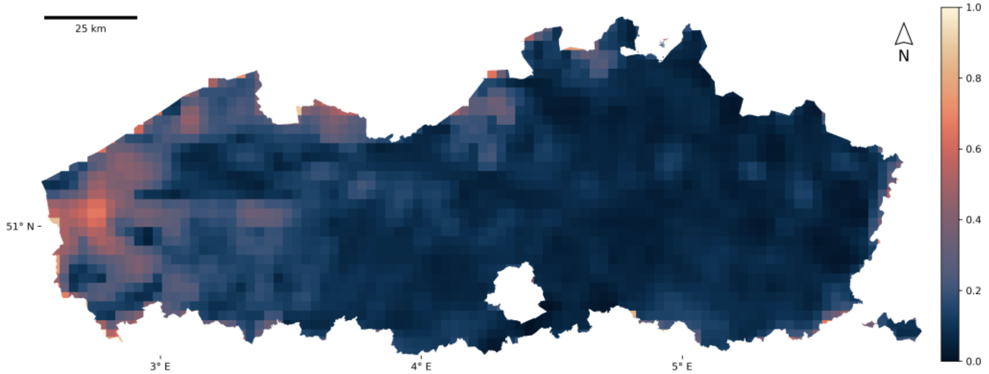
Land use map



(1) Current connectivity



(2) Improved connectivity



(3) Relative improvement (log)

Key takeaways

- Scalable, but not optimal solutions (yet?)
- Complementary to traditional tools
- Potential for spatial planning

Thank you!

Funding
Funded by Research Foundation Flanders (FWO), grant number 1S59525N

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References

Equihua, J., Beckmann, M., & Seppelt, R. (2024). Connectivity conservation planning through deep reinforcement learning. *Methods in Ecology and Evolution*, *15*(4), 779–790. https://doi.org/10.1111/2041-210X.14300

Hamonic, F., Vaxès, Y., Couëtoux, B., & Albert, C. H. (2025). GECOT: Graph-based ecological connectivity optimization tool. *Methods in Ecology and Evolution*, *16*(9), 1914–1922. https://doi.org/10.1111/2041-210X.70055