Iterative Modelling (Initial Model V.1)

Menorca Biodiversity Conservation Project

This first implementable version of the optimisation model is an early-stage connectivity formulation. It resembles a **network-flow-based habitat expansion model**, but uses a simplified and computationally tractable structure aligned with the code implementation.

The model does *not* construct full dynamic multi-commodity flows as in classical formulations. Instead, it uses:

- Binary habitat and restoration decisions,
- A budget-limited investment mechanism,
- A minimal flow-based constraint to prevent isolated habitat patches,
- Corridor activation constraints linking flow to the ecological network.

This simplified flow structure ensures basic ecological continuity.

Sets and Indices

- I: Set of grid cells (nodes).
- E: Set of undirected edges (u, v) between adjacent cells.
- $S = \{\text{atelerix, martes, eliomys, oryctolagus}\}$: set of species.
- $N(i)$: Neighboring cells of cell i (adjacent according to the input data).

Decision Variables

- $x_{i,s} \in \{0, 1\}$: 1 if cell i is active habitat for species s.
- $y_{i,s} \in \{0, 1\}$: 1 if restoration investment is made for species s in cell i.
- $z_{u,v} \in \{0, 1\}$: 1 if corridor (u, v) is activated.
- $f_{u,v,s} \in \mathbb{Z}_{\geq 0}$: simplified flow variable used to prevent isolated restorations.
- $\text{stress}_i \in \{0, 1\}$: conflict indicator.

Objective Function

The objective maximises accumulated habitat suitability and restoration gains, penalised by interspecific stress and corridor activation.

$$\max Z = \sum_{i \in I} \sum_{s \in S} A_i \left(Q_{i,s} x_{i,s} + \Delta Q_{i,s} y_{i,s} \right) \; - \; P_{\text{stress}} \sum_{i \in I} \text{stress}_i \; - \; \epsilon \sum_{(u,v) \in E} z_{u,v}.$$

Here:

- $Q_{i,s}$ is baseline suitability,
- $\Delta Q_{i,s} = \max(0,\, 3.0 - Q_{i,s})$ is the restoration gain,
- A_i is cell area

Constraints

1. Investment Logic

$$\begin{aligned} y_{i,s} &\le x_{i,s} && \forall i \in I,\ s \in S, \\ x_{i,s} &\le y_{i,s} && \forall i \in I,\ s \text{ non-native in } i. \end{aligned}$$

2. Budget Constraint

$$\sum_{i,s} C^{\text{adapt}}_{i,s} y_{i,s} \; + \sum_{(u,v) \in E} C^{\text{corr}}_{u,v} z_{u,v} \; \le \; B_{\text{total}}.$$

3. Biological Conflicts

$$x_{i,\text{martes}} + x_{i,\text{eliomys}} \le 1 \qquad \forall i \in I.$$

4. Connectivity Constraint (Simplified Flow)

$$\sum_{j \in N(i)} f_{j,i,s} - \sum_{j \in N(i)} f_{i,j,s} \; \ge \; x_{i,s} \qquad \forall i \in I,\ s \text{ non-native in } i.$$

5. Flow–Linkage Constraints (Big-M)

$$\begin{aligned} f_{u,v,s} &\le M\, z_{u,v} && \forall (u,v) \in E,\ s \in S, \\ f_{u,v,s} &\le M\, x_{u,s} && \forall (u,v) \in E,\ s \in S, \\ f_{u,v,s} &\le M\, x_{v,s} && \forall (u,v) \in E,\ s \in S. \end{aligned}$$

Where $M = |I|$.