Iterative Modelling (Model V.2)

Menorca Biodiversity Conservation Project

This second iteration originates from the practical limitations identified in Model V.1. The flow-based formulation, although conceptually aligned with classical connectivity models, quickly became computationally intractable. Even after long solver runtimes, no optimal solution was found, and the search frequently stagnated due to the heavy combination of flow conservation, Big-M dependencies, and species–specific propagation.

To overcome these bottlenecks, Model V.2 replaces dynamic flow construction with a Path Selection Strategy. For each species and each cell, a unique shortest path (topology–based) is pre–computed outside the optimisation model. Connectivity is enforced by requiring that all edges along that fixed path be activated whenever the corresponding cell is selected, eliminating the need for multi–commodity flows and significantly reducing model size.

Model V.2 should therefore be viewed as a tractable relaxation of V.1. It maintains the ecological requirement of network reachability, but avoids the prohibitive search space of dynamic routing, resulting in a model that solves consistently within realistic computational limits.

Sets and Indices

- I: Set of grid cells (nodes).
- E: Set of all edges connecting adjacent cells.
- S: Set of species $S = \{\text{atelerix, martes, eliomys, oryctolagus}\}$.
- $P_{i,s} \subseteq E$: Set of edges forming the shortest path to cell i for species s (Topological metric).

Parameters

- A_i: Area of cell i.
- $Q_{i,s}$: Habitat suitability.
- C_e^{corr}: Topological cost of edge e (assumed constant or proportional to adjacency).
- B_{total}: Budget.

Decision Variables

- $x_{i,s} \in \{0, 1\}$: 1 if cell i is selected.
- $y_{i,s} \in \{0, 1\}$: 1 if cell i is restored.
- $z_e \in \{0, 1\}$: 1 if edge e is activated.
- $\text{stress}_i \in \{0, 1\}$: 1 if conflict exists.

Objective Function

Maximize biodiversity score minus costs and stress (Identical to V.1):

$$\text{Maximize } \sum_{i\in I}\sum_{s\in S} W_s A_i \left(Q_{i,s}x_{i,s} + \Delta Q_{i,s}y_{i,s}\right) - \sum_{i\in I} P_{\text{stress}} \cdot \text{stress}_i - \sum_{e\in E} z_e$$

Constraints

1. Connectivity via Path Implication (New)

This constraint replaces the complex flow conservation laws. If a cell is selected, its specific pre-calculated access path must be paid for.

$$x_{i,s} \le z_e \quad \forall i,s,\forall e \in P_{i,s}$$

2. Simplified Equity (Naive)

At this stage, a generic equity constraint was introduced to ensure species diversity, but without biological calibration (equal targets for all species).

$$0.10 \cdot \mathcal{A}_{\text{total}} \le \sum_{i\in I} A_i x_{i,s} \le 0.40 \cdot \mathcal{A}_{\text{total}} \quad \forall s$$

Where $\mathcal{A}_{\text{total}} = \sum_{k\in S}\sum_{j\in I} A_j x_{j,k}$.

3. Investment Logic

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

4. Budget Constraint

$$\sum_{i,s} C^{\text{adapt}}_{i,s} y_{i,s} + \sum_{e\in E} C^{\text{corr}}_e z_e \le B_{\text{total}}$$

5. Biological Conflicts

$$x_{i,\text{martes}} + x_{i,\text{eliomys}} \le 1$$