Iterative Modelling (Final Model V.3)

Menorca Biodiversity Conservation Project

This final iteration arises from the practical shortcomings observed in Model V.2. While the path–selection approach introduced a major computational improvement, the use of topological distances led to unrealistic corridor geometries and biologically implausible connectivity patterns. The resulting solutions exhibited fragmented structures and corridor routes that were artefacts of grid adjacency rather than reflections of real landscape friction or spatial feasibility.

Model V.3 resolves these shortcomings by replacing the abstract grid–distance metric with a real geodetic cost surface. Shortest paths are now computed on a geographically weighted graph where edge costs integrate both spatial distance and landscape friction. This produces ecologically meaningful movement routes and eliminates the distortions introduced by uniform topological weights. The optimisation model itself remains compact, benefiting from the efficient path–implication structure previously developed.

As a result, Model V.3 delivers a realistic connectivity–driven optimisation framework that balances computational tractability with spatial accuracy. The geodetic preprocessing aligns corridor selection with the underlying terrain, allowing the model to produce habitat networks that are both solvable and ecologically credible.

Sets and Indices

- I: Set of candidate sites (grid cells).
- S: Set of species: $\{\text{atelerix}, \text{martes}, \text{eliomys}, \text{oryctolagus}\}$.
- E: Set of all potential corridor edges.
- $P_{i,s} \subseteq E$: Pre-computed shortest path from the nearest existing population core of species s to site i. May be empty or undefined.

Parameters

- A_i: Area of site i.
- $Q_{i,s}$: Baseline habitat suitability.
- $\Delta Q_{i,s} = \max(0,\, 3.0 - Q_{i,s})$: Fixed suitability gain after restoration (the model sets restored quality to 3.0).
- $C_{i,s}^{\text{adapt}}$: Adaptation cost for species s at site i.
- C_e^{corr}: Corridor cost for activating edge e.
- W_s: Species-specific weight.
- P_{stress}: Penalty applied to interspecific conflict.
- $\epsilon = 1$: Corridor usage penalty used to break ties (fixed to 1 in the implementation).

- B_{total}: Total available budget.

Decision Variables

- $x_{i,s} \in \{0,1\}$: 1 if site i is active habitat for species s.
- $y_{i,s} \in \{0,1\}$: 1 if site i receives restoration for species s.
- $z_e \in \{0,1\}$: 1 if corridor edge e is activated.
- $\text{stress}_i \in \{0,1\}$: Interspecific conflict indicator.

Objective Function

The final score maximised by the model is:

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

The term $-y_{i,s}$ is included inside the double sum to apply a small penalty to each restoration action, discouraging unnecessary investments unless the ecological gain compensates for it.

Notes on objective alignment with implementation

- The implementation adds the restoration benefit term $W_s A_i \Delta Q_{i,s} y_{i,s}$ and simultaneously applies a small penalty $(-1)\, y_{i,s}$, exactly reflected in the grouped expression inside the double sum.
- ϵ is implemented as a fixed value $\epsilon = 1$.

Constraints

1. Investment Logic

$$y_{i,s} \le x_{i,s} \quad \forall i, s$$

If a species is not originally present at i, restoration is mandatory:

$$x_{i,s} \le y_{i,s} \quad \forall i, s \text{ where species } s \text{ is non-native at } i$$

2. Connectivity via Path Implication

If site i is activated for species s, all edges in its pre-computed path must be activated:

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

If no feasible path exists ($P_{i,s} = \emptyset$), the implementation enforces:

$$x_{i,s} = 0.$$

3. Corridor Activation Costs

Corridor costs appear only in the budget and objective but do not impose additional structural constraints beyond path implications.

4. Budget Constraint

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

5. Biological Equity Constraints

Let the total conserved area be:

$$A_{\text{total}} = \sum_{k\in S}\sum_{j\in I} A_j x_{j,k}$$

For each species s:

$$\text{MinPct}_s \cdot A_{\text{total}} \;\le\; \sum_{i\in I} A_i x_{i,s} \;\le\; \text{MaxPct}_s \cdot A_{\text{total}}$$

6. Interspecific Conflict

Martes–Eliomys exclusion:

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

Stress penalisation between Martes and Oryctolagus is implemented as:

$$\text{stress}_i \ge x_{i,\text{martes}} + x_{i,\text{oryctolagus}} - 1$$