D 1.2 REWILDING POTENTIAL AND PRIORITY REGIONS

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Executive summary

This deliverable develops a spatially explicit framework to guide smart rewilding choices in the Alpine Convention area of Italy. The analysis integrates wildfire history, forest carbon stock, and CORINE-based forest and afforestation structure on a common 50 km^2 grid. Its objective is to support transparent territorial prioritization rather than producing a one-size-fits-all prescription. In this version of the model, three smart rewilding scenarios are activated only in forest cells with high carbon stock, while low-carbon forest cells are assigned to business as usual (BAU).

The analysis covers 1,184 grid cells, the majority of which 50 km^2 (excluding peripherical ones), for a total of > 50,000 km^2. Of these, 28.4% are forest-eligible. In the final allocation, BAU accounts for 51.1% of the area, while smart rewilding pathways cover the remaining share: directed spontaneous rewilding (St_R) includes 44.3% of the area, fire-smart rewilding with direct prevention (FSR_DP) 3.3%, and fire-smart rewilding with direct + indirect prevention (FSR_DIP) 1.4%.

St_R forms the largest and most continuous rewilding pattern, particularly across the central-eastern Alpine sector, and therefore represents the territorial backbone of the strategy. FSR_DP emerges as a concentrated set of hotspots where high carbon overlaps with stronger fire signal, making direct prevention measures more strongly justified. FSR_DIP is intentionally selective, identifying niche locations where high carbon, fire-related pressure, and afforestation context converge and where integrated prevention can be strategically prioritized.

The resulting decision message is differentiated. The framework supports broad process-oriented rewilding where risk conditions are compatible; targeted direct prevention where fire pressure is more pronounced; and highly selective integrated prevention where local context warrants intensified intervention. The output should be interpreted as a propensity map rather than a deterministic operational plan. Site-level implementation will require a tiered planning approach: first screen areas by eligibility, then calibrate intervention intensity according to the assigned scenario.

In synthesis, the deliverable provides a robust and reproducible basis to align rewilding pathways with wildfire containment objectives, while safeguarding long-term carbon retention. Before operational deployment, additional considerations - including access constraints, ownership fragmentation, operational feasibility, expected costs, institutional capacity, and local social acceptance - should be integrated into final intervention programming.

Keywords

Rewilding; Alpine space; land-use change; carbon sink; forest fire; afforestation; proforestation; landscape mosaic; adaptive forest governance.

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1. Introduction

Rewilding can be defined as a trajectory-oriented approach to ecosystem recovery that prioritizes self-sustaining ecological processes, natural regeneration, and long-term landscape resilience, while reducing dependence on continuous intensive management (Wang et al. 2025). More specifically, according to Perino et al. (2019), rewilding is a conservation approach that restores ecosystems by re-establishing natural processes, reducing human control, and enabling trophic complexity to recover. It emphasizes process-based management, allowing ecological dynamics — such as natural disturbance (i.e., fires), species interactions, and dispersal — to shape resilient landscapes over time. However, in Mediterranean and Alpine socio-ecological systems, rewilding cannot be interpreted as a uniform withdrawal of intervention (Bugalho et al. 2026). Where fuel continuity, ignition pressure, and exposure are high, unmanaged biomass accumulation may increase the probability of large, high-severity fires, with direct losses of carbon stocks, habitat quality, and structural complexity. For this reason, rewilding strategies need to be explicitly fire-aware: ecological restoration goals must be aligned with fire-spread prevention so that carbon retention and biodiversity gains are maintained over time rather than periodically reversed by severe disturbances. Within this logic, fire-smart rewilding combines process-based ecological recovery with targeted prevention configurations, ensuring that interventions are proportionate to wildfire pressure and consistent with the expected long-term delivery of climate and biodiversity benefits. Moreover, in Mediterranean and Alpine regions, where long-standing cultural landscapes hold significant conservation importance, the abandonment or decline of traditional management practices can lead to biodiversity loss rather than ecological recovery.

Wildfire regimes in Europe are changing in ways that directly affect forest resilience, carbon stability, and landscape safety (Patacca et al. 2022). In the Italian Alpine space, this trend intersects with long-term land-use transitions, including forest expansion on formerly managed or abandoned land, increasing structural continuity of fuels, and growing exposure of high-value ecosystem services. Under these conditions, wildfire prevention cannot be treated as a stand-alone emergency function. It needs to be embedded in a broader spatial strategy that links risk reduction, ecological dynamics, and carbon stewardship.

This deliverable develops a spatial decision-support product to estimate the **propensity for optimal rewilding** across the Italian area of the Alpine Convention, using a 50 km^2 grid as the common assessment unit. The product is designed to support consistent prioritization across large territories while remaining interpretable for regional and sub-regional planning workflows. All grid cells are retained in the database to preserve full spatial continuity. Forest representativeness is explicitly tracked through calculation of the forest cover fraction in each pixel, which allows transparent filtering and interpretation rather than implicit exclusion. The methodological framing follows the scenario architecture already established in the previous REWILDFIRE deliverables (see Deliverable 1.1 for a full description of each scenario), and applies the same operational interpretation of rewilding pathways:

- **Business as usual (BAU)**: spontaneous rewilding. If carbon stock is not particuarly high, no fire-smart rewilding strategy is suggested, i.e., BAU land management, including afforestation and proforestation of economically unviable and abandoned land (but not necessarily high carbon).
- **Strict rewilding (St_R)**: trajectory centered on natural development and low-intervention dynamics where wildfire pressure is relatively low, forest carbon stocks are high and proforestation can proceed with limited direct prevention intensity.

- **Fire-smart rewilding with direct prevention (FSR_DP)**: trajectory for forest cells with relevant carbon value and elevated fire pressure, where direct risk-reduction actions are prioritized, i.e., by designing a network of firebreaks.
- **Fire-smart rewilding with direct + indirect prevention (FSR_DIP)**: trajectory for forest cells with relevant carbon value and elevated fire pressure that also include a minimum presence of post-2000 afforestation, where direct actions are combined with broader landscape-level preventive configuration, i.e., by increasing the agro-forest mosaic and converting young secondary forests (<25 years old) back to cropland or permanent meadows.

The fire-smart rewilding approach therefore requires the integrated interpretation of at least three dimensions: **Disturbance pressure** (historical wildfire frequency), **Ecological-climatic value at risk** (forest carbon stock), **Structural/trajectory context** (forest age structure and afforestation pattern). Bringing these components together within a single, harmonized framework allows the resulting cartography to inform differentiated prevention strategies rather than applying a uniform strategy across all forest areas.

The objective is to produce an operational map-based product that: (1) integrates wildfire history (2007-2024), forest carbon stock (reference year: 2020), and CORINE-derived forest/afforestation information (reference years: 2000-2018); (2) estimates cell-level propensity for the three rewilding scenario policies (FSR_DIP, FSR_DP, St_R); (3) supports subsequent technical discussion on where direct prevention, combined direct+indirect prevention, or spontaneous rewilding logic are more coherent with local conditions.

At the same time, the product has clear defined boundaries. It does not encode operational constraints such as access logistics, local treatment costs, ownership fragmentation, or social acceptability. Those elements should be integrated in subsequent prioritization rounds. The value of this deliverable lies in establishing a transparent first-order spatial logic that is scientifically grounded and readily extensible.

2. Input data and methods

The workflow integrates four primary data domains, consistent with the scenario logic developed in the other project's deliverables.

Afforestation layer (post-2000): afforestation polygons (post-2000; Minimum mapping unit 5 ha) were derived from CORINE Land Cover (CLC) change layers for Italy Italy (periods 2000-2006, 2006-2012, and 2012-2018). The dataset includes only polygons that transitioned from non-forest CLC classes to forest classes 311, 312, and 313, thus representing secondary forest established after 2000. For each spatial cell, afforestation presence and intensity were quantified as affo_frac, defined as the proportion of the cell area covered by post-2000 afforestation polygons. This parameter serves as a discriminant variable to distinguish FSR__DIP from FSR__DP and St__R. The selected polygons represent forest stands existing in 2018 with an estimated age ≤ 25 years at the time of writing.

Forest cover layer (CLC 2018): CLC 2018 polygon layer for Italy was used to derive forest cover information. The selected classes were 311 Broad-leaved forest, 312 Coniferous forest, 313 Mixed forest. This layer was used to calculate forest area in hectares and forest fraction within each cell, to define the forest mask for carbon stock aggregation; and provide the forest background layer for the final cartographic outputs.

Wildfire layer (2007-2024): wildfire perimeter polygons for Italy, 2007-2024 were provided by the PRIN PNRR project "FIREBOX" coordinated by University of Milan[1]. This dataset was used to calculate cell-level wildfire frequency, computed as count of distinct fire polygons intersecting each grid cell.

Carbon stock raster (2020): the aboveground carbon stock raster at 100 m resolution (year 2020) was provided by the national high institute for the protection and research on the environment (ISPRA). This dataset was used to calculate cell-level mean aboveground carbon stock, calculated over the forested fraction of each cell (i.e., the area intersecting CLC 311–313). The resulting value serves as a trigger variable to inform the selection between rewilding strategies and BAU forest management.

All vector layers were transformed to a common projected coordinate reference system with metric units, and raster layers were reprojected to the same reference system. Geometries were validated prior to intersection to minimize topology errors during in overlay operations. All thematic layers (afforestation, CLC forest, fire perimeters, carbon raster) were clipped or masked to the Italian Alpine Convention area prior to aggregation. Then, a 50 km^2 square grid was generated over the study area and intersected with the study boundary. Each grid cell was assigned a unique identifier and its effective area in hectares was calculated, accounting for edge cells partially intersected by the perimeter.

- **Forest area per cell** was computed by intersecting each grid cell with CLC 2018 forest classes 311, 312, 313 and summing intersected area. This variable defines forest eligibility and is also reported in final outputs for transparency. Forest fraction was then calculated as:

$$\text{forest\_frac} = \frac{\text{forest\_area\_ha}}{\text{cell\_area\_ha}}.$$

- **Afforestation area per cell** (`affo_area_ha`) was computed from the post-2000 afforestation polygon layer. The afforestation fraction was derived as:

$$\text{affo\_frac} = \frac{\text{affo\_area\_ha}}{\text{cell\_area\_ha}}.$$

- **Wildfire frequency** was measured as the number of distinct fire polygons intersecting each cell over 2007-2024. This produces a cumulative disturbance-pressure indicator at 50 km scale.
- **Carbon stock** (tC/ha) was aggregated from raster to grid through area-weighted extraction on the forested part of each cell (intersection with CLC forest polygons). This ensures that carbon values reflect forest land rather than mixed land uses within the same cell.

[1] https://doi.org/10.5281/zenodo.11528284

Two binary masks were used before score calculation:

1. **Forest cell mask** – a cell was considered forest-eligible if forest_frac $\geq \tau_f$, where $\tau_f$is the minimum forest fraction threshold (set to 0.01, or 50 hectares of forest per cell)
2. **Minimum afforestation mask** – a cell was considered afforestation-positive if affo_frac $\geq \tau_a$, where $\tau_a$is the minimum afforestation fraction threshold (set to 0.001 or 5 hectares of young secondary forests, i.e. on minimum mapping unit).

To combine all variables on a comparable scale, fire frequency and carbon stock were normalized to $[0, 1]$using robust percentile scaling:

$$x_n = \text{clip}\left(\frac{x - P5}{P95 - P5}, 0, 1\right)$$

where $P5$and $P95$are the 5th and 95th percentiles of the variable distribution over eligible forest cells. This normalization limits outlier influence while preserving relative ranking.

Outputs are F_n: normalized fire frequency, C_n: normalized carbon stock, and $1 - F_n$: low-fire complement for St_R. A forest cell is classified as high-carbon if $C_n \geq \tau_C$, and low-carbon otherwise. In the current implementation, $\tau_C$is set as the median (50th percentile) of $C_n$across forest-eligible cells (alternative fixed thresholds may be chosen). To choose the best rewilding policy for each pixel, propensity scores were computed with equal weights on carbon and fire terms ($w_C = 0.5$, $w_F = 0.5$). Assigning equal weights (0.5) reflects a neutral approach, where carbon sequestration and fire risk reduction are considered equally important. Increasing the weight on carbon implies a stronger emphasis on climate mitigation, prioritizing strategies that maximize carbon storage and sequestration. Conversely, assigning a higher weight to fire risk reduction reflects a focus on adaptation and risk management, favoring policies that enhance landscape resilience and reduce the likelihood or severity of wildfires. Therefore, changing the weights does not simply adjust the model mechanically, but it effectively shifts the underlying policy objective guiding the selection of fire-smart rewilding strategies.

- FSR_DIP (direct + indirect prevention): activated only where high carbon and minimum afforestation coexist:

$$I_{FSR\_DIP} = \begin{cases} w_C C_n + w_F F_n, & \text{if } is\_high\_Carbon\ AND\ has\_min\_affo \\ NA, & \text{otherwise} \end{cases}$$

- FSR_DP (direct prevention): activated where high carbon is present but afforestation is below threshold, or with no afforestation in the last 25 years:

$$I_{FSR\_DP} = \begin{cases} w_C C_n + w_F F_n, & \text{if } s\_high\_Carbon\ AND\ \text{NOT}\ has\_min\_affo \\ NA, & \text{otherwise} \end{cases}$$

- St_R (spontaneous rewilding): activated where high carbon is present, afforestation is below threshold, and lower fire pressure is favored:

$$I_{StR} = \begin{cases} w_C C_n + w_F (1 - F_n), & \text{if } is\_high\_Carbon\ AND\ \text{NOT}\ has\_min\_affo \\ NA, & \text{otherwise} \end{cases}$$

BAU is defined explicitly as the default option for low-carbon forest cells: $scenario = BAU$ if is_low_carbon. For high-carbon cells, the final rewilding scenario is assigned by maximum score among available I_{FSR_DIP}, I_{FSR_DP}, and I_{StR}. If no rewilding score is available, fallback assignment is BAU. As described in Deliverable 1.1, in this scenario fire suppression remains at historical baseline level, forests are mostly un-managed and agriculture follow full aging/abandonment trajectories.

3. Results and discussions

The final output includes **1,180 grid cells** (50 km^2 in size) across the Italian Alpine. Convention domain. Of these, **28.4%** meet the forest eligibility threshold. By design, the carbon-stock rule splits forest-eligible cells almost evenly:

- **High-carbon forest cells**: **48.9%** of forest cells
- **Low-carbon forest cells**: **51.1%** of forest cells

The final scenario map (Figure 1) reveals a strongly structured allocation, shaped by the carbon-threshold rule and by the sequential activation logic used for rewilding pathways. At first glance, the dominant pattern is the extensive coverage of **BAU**, which accounts for 51**.1%** of the total grid. This prevalence is expected under the current setup and should not be interpreted as a lack of ecological opportunity. It reflects a deliberate rule: smart rewilding scenarios are activated only where landscape cells meet the forest cover threshold **and** high-carbon condition. In all other cases, including low-carbon forest cells and non-forest cells, the model assigns BAU by design (i.e., fire suppression remains at historical baseline level, forest remains largely un-managed and agriculture follows historical aging/abandonment trajectories).

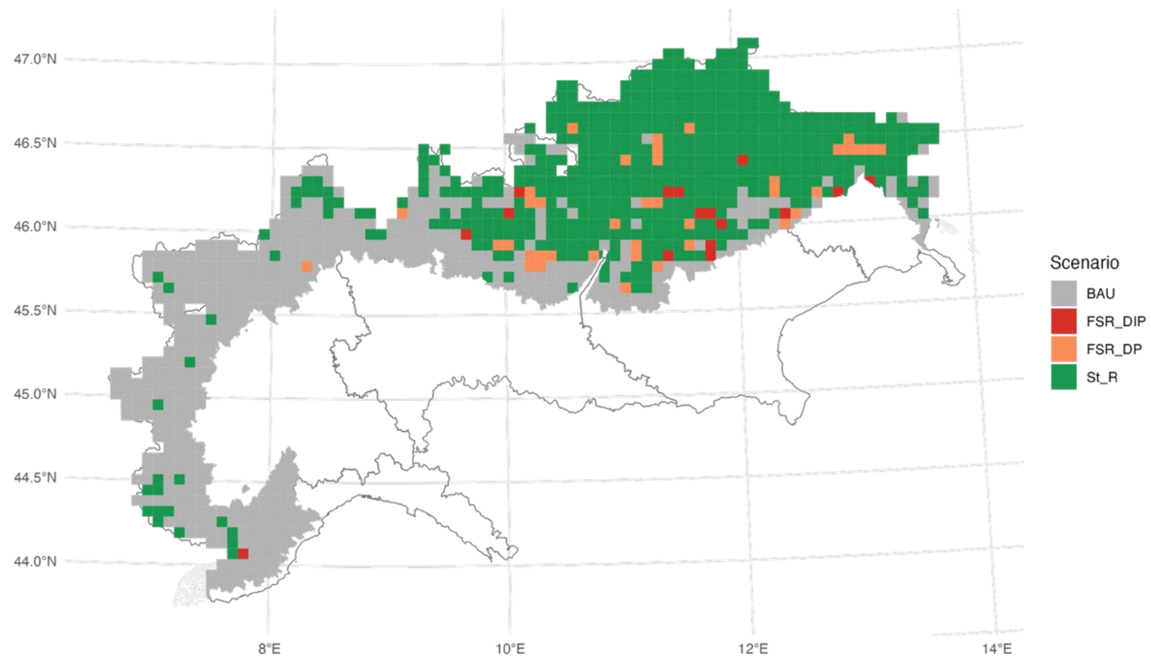

Figure 1 – Best rewilding alternative in the italian Alpine space

Within the remaining share, smart rewilding outcomes show clear differentiation.

St_R is by far the most extensive pathway, with **44.3%** of the total. Spatially, this forms the only rewilding pattern that is broad enough to create recognizable territorial continuities rather than isolated points. In practical terms, this indicates that once high-carbon eligibility is met, the most common outcome is still the pathway associated with lower relative fire pressure and spontaneous rewilding dynamics (**proforestation**).

FSR_DP is much more selective, encompassing only **3.3%** of all cells. These cells correspond to locations where high carbon value coexists with higher fire pressure, but where afforestation fraction remains below the FSR_DIP threshold. The small size of this class is informative: direct prevention is not distributed diffusely across the landscape in this model version, but concentrated in a limited set of high-priority locations. For a decision-making perspective, FSR_DP defines a compact portfolio of cells where risk-oriented interventions are most justified under the current assumptions.

FSR_DIP is the rarest outcome, with **1.4%** of the total. This class requires the simultaneous occurrence of several restrictive conditions: high carbon, fire-relevant score activation, and minimum afforestation presence. Its low frequency is therefore structurally coherent with the model logic. Rather than indicating weak model performance, it indicates that the integrated direct+indirect prevention pathway is **reserved for very specific territorial configurations**. A methodological limitation of the FSR_DIP scenario is that its activation requires a minimum fraction of post-2000 afforestation, which may introduce a territorial bias toward more recent afforested areas and reduce the inclusion of potentially relevant hotspots characterized by mature forests or older afforestation; however, the identification of carbon- and fire-risk hotspots remains possible under the other rewilding scenarios.

From a policy and management perspective, the model does not support a uniform "best" rewilding strategy across the entire domain. Instead, it points to a layered approach: **a broad St_R backbone where conditions are favourable, a narrower FSR_DP set where risk warrants direct prevention, and a very selective FSR_DIP subset where afforestation context and risk patterns justify integrated prevention**. The resulting allocation is therefore conservative, explicit, and immediately usable for prioritization discussions, because each scenario class corresponds to a distinct combination of ecological value and fire-related pressure.

The **spatial configuration of optimal rewilding choices** shows a clear longitudinal gradient along the Italian Alpine arc, with scenario propensity increasing from patchy western signals to broader and more continuous structures in the central-eastern sector. This pattern is visible in all three scenario families, but with different intensity, continuity, and fragmentation.

In the **St_R maps** (continuous and quantile), the dominant visual feature is spatial continuity. Medium-to-high values are not limited to isolated pixels, but form extended bands, especially across the central and eastern Alpine belt. The western portion remains more discontinuous, with scattered cells and weaker clustering. This indicates that where the carbon threshold is satisfied, the low-fire-oriented pathway tends to occupy coherent territorial blocks. In practical terms, St_R behaves as the "matrix" scenario: it provides the broadest rewilding geography and connects multiple subareas that would otherwise appear disconnected under prevention-focused classes.

The **FSR_DP maps** exhibit a markedly different spatial geometry. Values are concentrated in narrower corridors and local hotspots, mostly superimposed on areas where fire pressure is comparatively stronger. The central-east still dominates, but the footprint is less continuous than in St_R and punctuated by abrupt transitions. In the class map, upper quantiles (Q4-Q5) appear as compact nuclei surrounded by moderate classes, rather than as large continuous fields.

The **FSR_DIP pattern** is the most restrictive and fragmented. The map compromises a very small number of cells, mostly isolated or forming tiny clusters along the southern Alpine edge, with clear concentration in limited central-eastern locations and almost no broad areal continuity elsewhere. Relative to St_R and FSR_DP, the spatial signal is sparse by design. The afforestation condition acts as a strong filter, so FSR_DIP appears only where local context meets all constraints simultaneously.

A second spatial difference apparent in the figures is the **contrast between core and edge behavior**. Core Alpine sectors exhibit denser rewilding activation and greater class variability, whereas edge sectors and marginal cells are more often assigned to BAU or low-intensity classes. This is pattern reflects the combined influence of forest eligibility, carbon gating, and afforestation thresholding, which are more difficult to satisfy in fragmented edge contexts.

Overall, the maps suggest a territorial structure organized around three nested spatial regimes:

1. **Extensive St_R** in high-carbon, lower-fire contexts, in central-eastern Alpine sectors;
2. **Targeted FSR_DP** in localized high-carbon, higher-fire hotspots, and
3. **Niche FSR_DIP** in very specific high-carbon areas with qualifying afforestation signal, both along the souther, exterior pre-alpine edge.

4. Conclusions and recommendations

This deliverable produced a reproducible 50 km^2 decision-support map for optimal rewilding in the Italian Alpine Convention area, integrating wildfire history (2007-2024), forest carbon stock (2020), and CLC-derived forest/afforestation structure. The updated methodological choice, a carbon-stock threhsold rule, proved decisive in shaping the final allocation. The map resolution is user-adaptable and can be refined in order to inform finer scale fire-smart rewilding planning. Overall, the results support a non-uniform territorial strategy: extensive spontaneous rewilding where conditions allow, direct fire prevention in focused hotspots, and integrated direct+indirect prevention only in niche contexts. The main conclusions are:

1. **The carbon stock is the primary allocation driver.** Fire-smart rewilding pathways are activated only in high-carbon forest cells, while low-carbon forest cells are assigned to BAU. This creates a conservative allocation that prioritizes safeguarding existing carbon value.
2. **St_R is the dominant smart rewilding option by area.** Among non-BAU scenarios it provides the broadest and most continuous territorial pattern, especially in the central-eastern Alpine belt.
3. **FSR_DP is selective and hotspot-oriented.** FSR_DP identifies a limited set of high-priority cells where high carbon co-occurs with stronger fire pressure in areas below the afforestation threshold.

4. **FSR_DIP is highly targeted.** FSR_DIP emerges in a very small number of cells because it requires a simultaneous combination of high carbon, fire-relevant conditions, and minimum afforestation presence. Its rarity is methodologically coherent.

In practical planning terms, St_R can support a wide process-based strategy across high-carbon areas with comparatively lower fire signal, coupled with monitoring and adaptive checks rather than systematic intensive treatment. FSR_DP should be treated as a targeted risk-management portfolio, focused on localized hotspots where high carbon and higher fire pressure overlap. FSR_DIP should be interpreted with even greater selectivity. Its low spatial coverage is coherent with the rule set and identifies a small set of sites where integrated direct and indirect prevention can be justified by local afforestation context and risk profile. These cells are appropriate candidates for deeper design work, site verification, and inter-institutional coordination.

Before translating this allocation into binding priorities, **sensitivity analysis** should be carried out. Thresholds and weights materially influence the extent and location of scenario classes, especially for FSR_DIP. Testing alternative values for afforestation threshold, carbon gate, forest eligibility, and variable weights is necessary to identify stable priorities versus parameter-dependent outcomes. The workflow already supports this quickly, because heavy preprocessing does not need to be repeated for each test.

Finally, access constraints, ownership fragmentation, operational feasibility, expected costs, institutional capacity, and local social acceptance should be added before final intervention programming. This integration is essential to move from “propensity” to **actionable plans** that can be implemented at scale and maintained over time.

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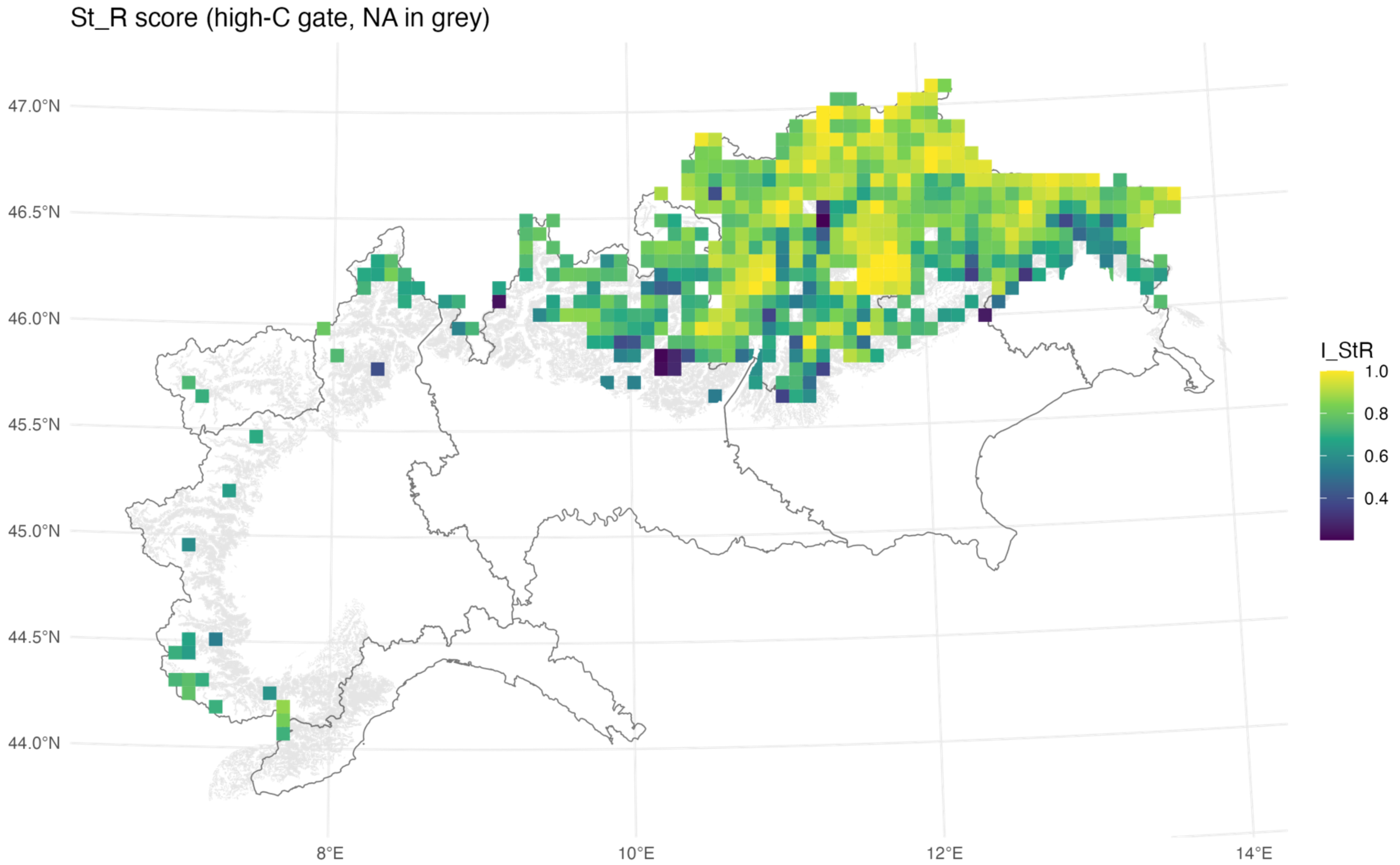
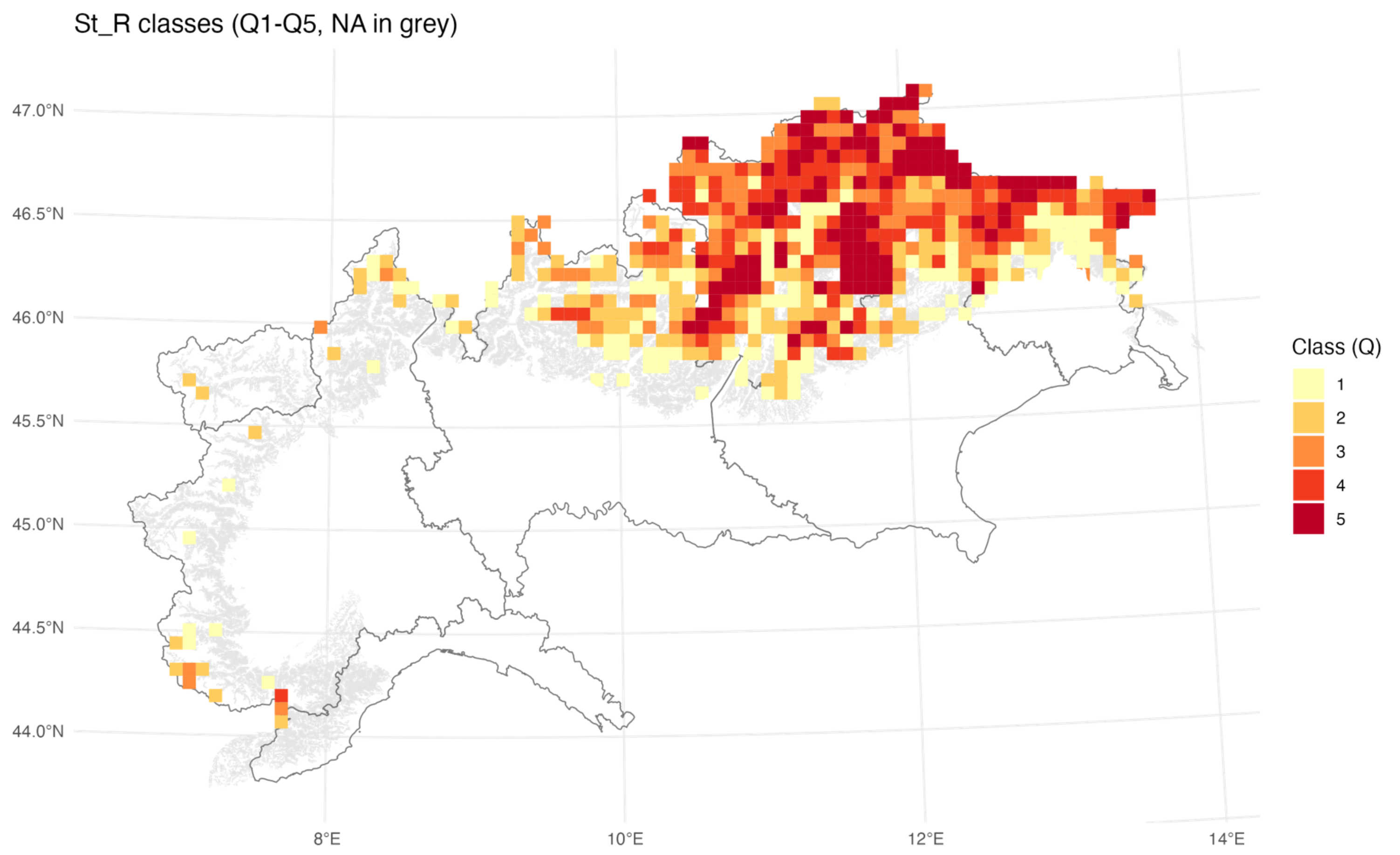
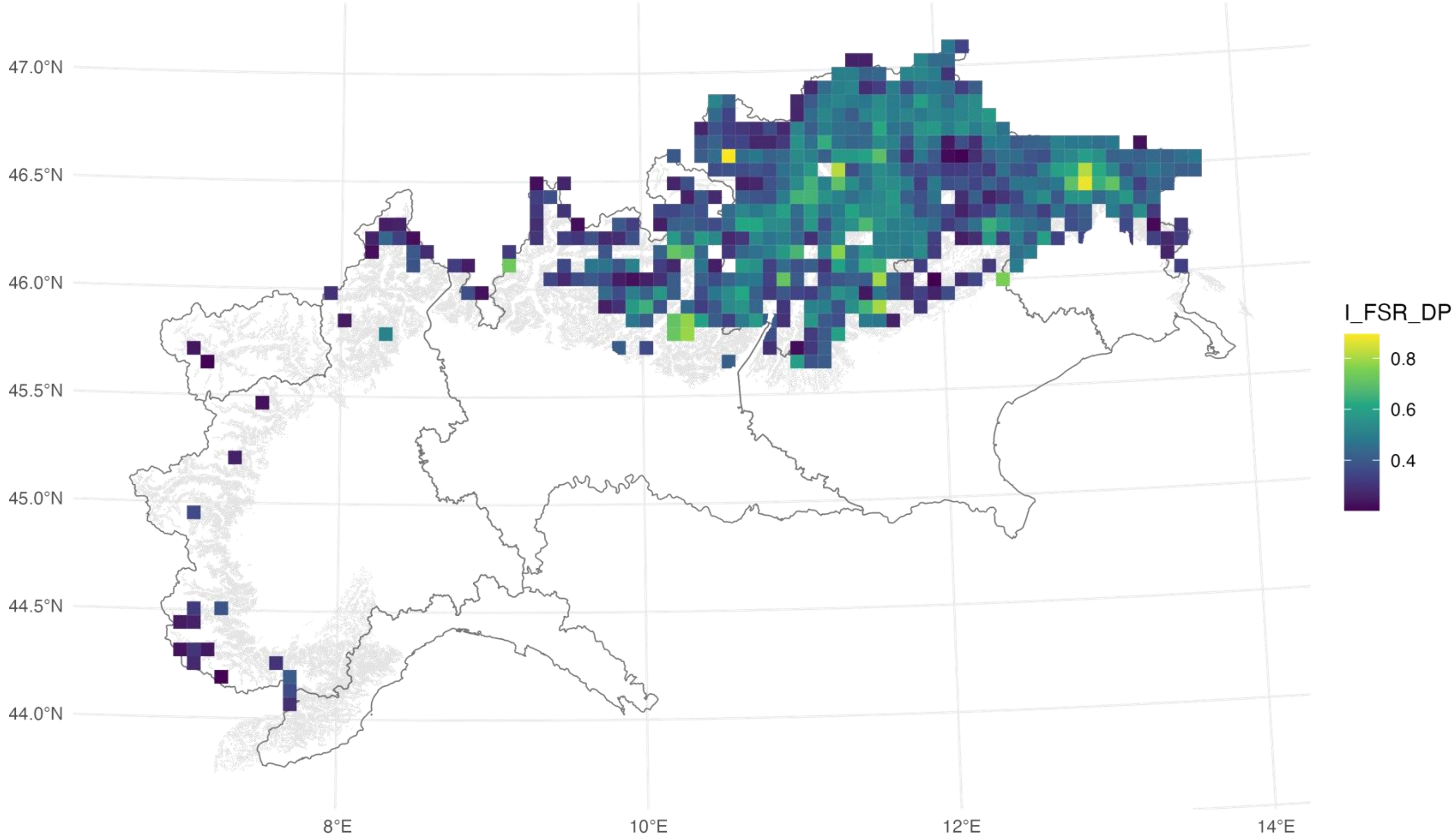
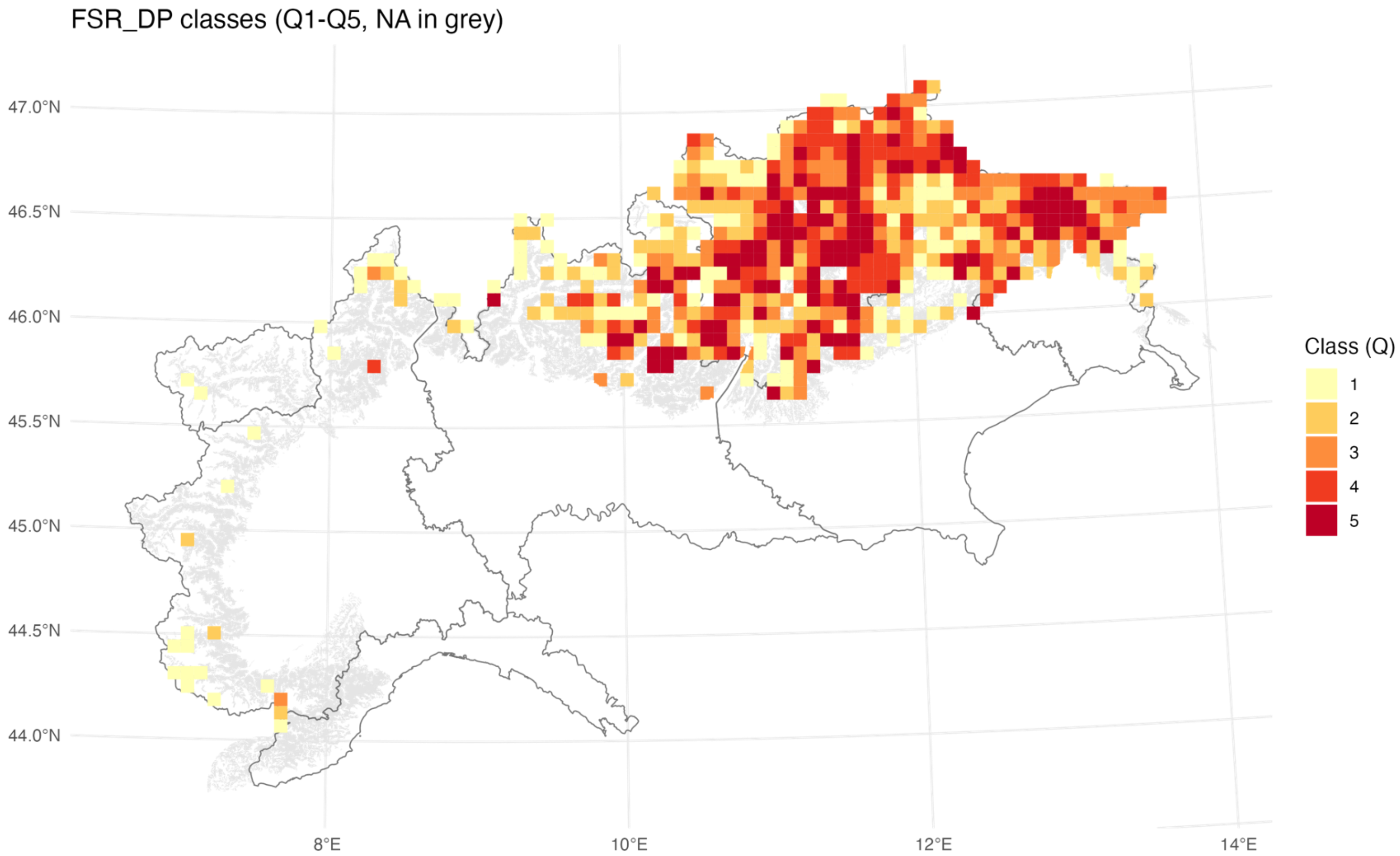
Annex – Suitability maps for each rewilding scenario




St_R classes (Q1-Q5, NA in grey)
47.0°N
46.5°N
46.0°N
45.5°N
45.0°N
44.5°N
44.0°N
8°E
10°E
12°E
14°E
Class (Q)
1
2
3
4
5

FSR_DP score (high-C gate, NA in grey)

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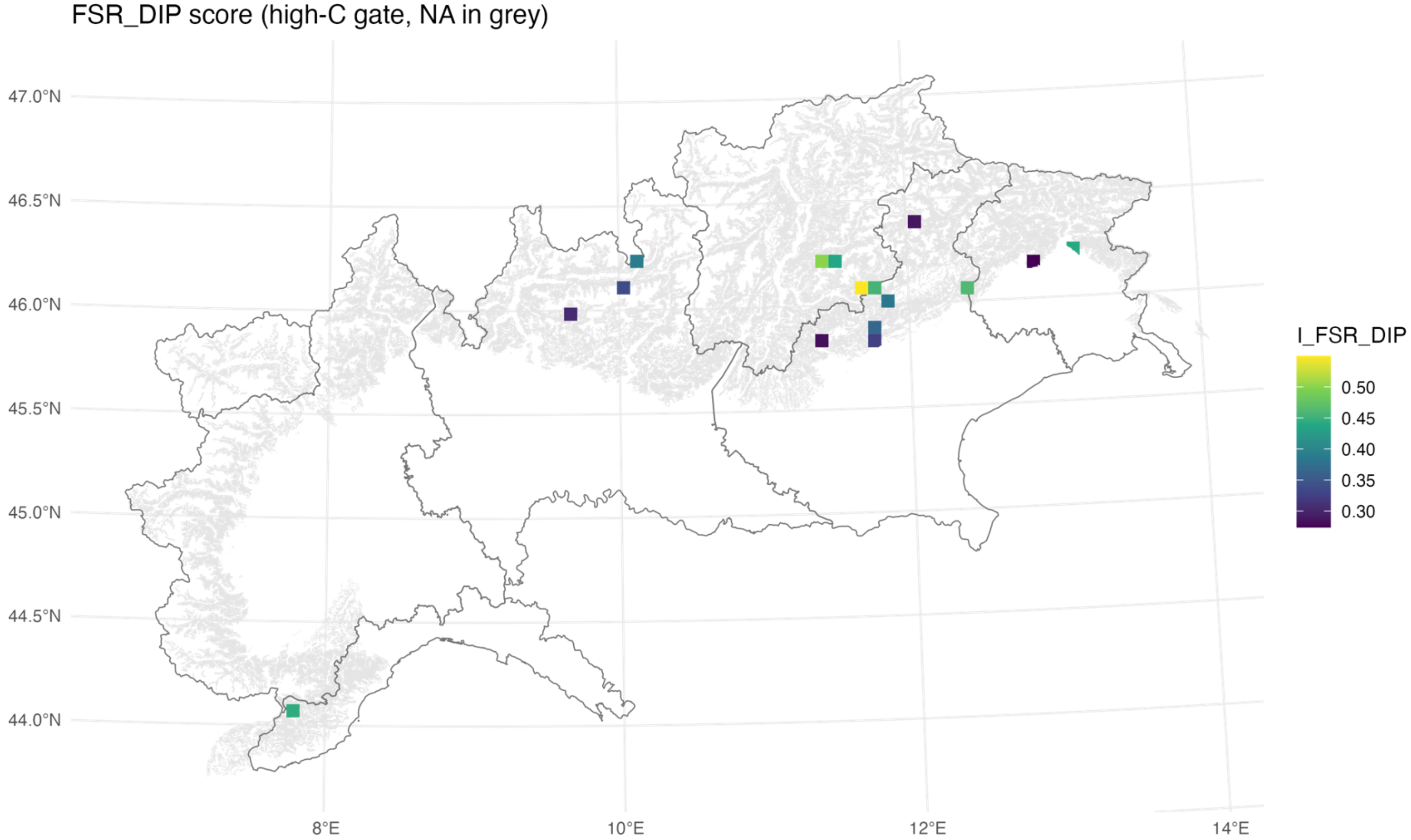
46.0°N
45.5°N
45.0°N
44.5°N
44.0°N
8°E
10°E
12°E
14°E
Class (Q)
1
2
3
4
5


FSR_DIP score (high-C gate, NA in grey)
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46.5°N
46.0°N
45.5°N
45.0°N
44.5°N
44.0°N
8°E
10°E
12°E
14°E
I_FSR_DIP
0.50
0.45
0.40
0.35
0.30

FSR_DIP classes (Q1-Q5, NA in grey)