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Improvement of the conservation status of forest habitats in the Mediterranean Biogeographical Region applying restoration and conservation techniques and *Close to Nature* management

Deliverable 3.2

Technical operational methodological report for silvicultural interventions suitable for reducing fire risk and compatible with conservation objectives for two habitats of the project

WP3 - Tools for Close to Nature Forest management

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Abstract

Deliverable D3.2 develops a conceptual framework and replicable methodology to assess the coherence, trade-offs, and potential conflicts between biodiversity conservation and wildfire prevention at both stand and landscape scales. The deliverable focuses on integrating habitat conservation targets—especially within Natura 2000 sites—with effective fire risk mitigation strategies, while balancing the preservation of key ecosystem services and civil protection priorities.

At the stand scale, the deliverable distinguishes between two types of preventive infrastructure: (i) shaded fuelbreaks, linear infrastructures designed to reduce flame intensity and enhance the safety and efficiency of firefighting operations, and (ii) self-resistance zones, where silvicultural treatments aim to increase the resistance and resilience of forests to fire disturbance in areas delivering essential functions (e.g. biodiversity hotspots, soil protection, seed source continuity). These interventions, tailored to vegetation type and expected fire behaviour, include thinning, fuel reduction, and structural modifications without compromising critical ecosystem services.

A key innovation of Deliverable D3.2 is the assessment of how silvicultural practices developed for biodiversity conservation (e.g. in the "Biodiversity Islands intervention protocol") align with fire prevention needs. The analysis, applied to fire-prone Habitat Types (HTs) and Islands of Biodiversity (IBs), evaluates the compatibility of conservation-oriented prescriptions with fuelbreak construction and stand resilience enhancement. Trade-offs are examined—particularly in smaller IBs where fire prevention must be considered throughout, and in larger ones, where targeted perimeter treatments are guided by predicted flame behaviour and habitat sensitivity.

At the landscape scale, the deliverable introduces a strategic planning approach supported by decision support systems based on fire propagation modelling. Wildfire hazard and exposure are assessed in terms of flame length, intensity, and the presence of vulnerable features such as wildland-urban interfaces and ecosystem services (biodiversity, soil protection, carbon storage). Informed by these analyses, spatial optimization techniques are used to prioritize areas for treatment, with infrastructure investment limited to 1% of the burnable area—mirroring current operational practices in the pilot territories of Pratomagno (Italy) and Prades (Spain).

To explore how conservation goals interact with fire risk reduction, four alternative planning scenarios were tested: (i) PRE (no prevention), (ii) BAU (business-as-usual, with no conservation priority), (iii) BIO (biodiversity-focused), and (iv) TRADE-OFF (a balanced compromise between conservation and general fire prevention). These scenarios offer a replicable method for evaluating where to site preventive infrastructure to simultaneously minimize fire risk and maximize conservation outcomes.

Overall, Deliverable D3.2 provides a spatially explicit, multi-scale planning framework that harmonizes wildfire prevention with biodiversity objectives, enabling informed decision-making under resource constraints. Tested across diverse pilot landscapes, this approach supports the creation of fire-resilient socio-ecological systems both within and beyond protected areas.

1. Introduction

Deliverable D3.2 develops a conceptual framework and a replicable methodology for assessing the coherence, potential conflicts and trade-offs between **biodiversity conservation** and **fire prevention** at the **stand** and **landscape** scales.

The **stand scale** addresses the **integration between** silvicultural **prescriptions** for the conservation of biodiversity in **Natura 2000 habitats** and prescriptions aimed at reducing the flammability of forest stands **within preventive infrastructures**. In deliverable D3.2, preventive infrastructures are grouped into two groups: (i) **strategic areas to support active fighting**, where firefighting operators can stand to extinguish the fire safely and more effectively in **defence of targets**, such as an island of senescence or an urban-rural interface area; (ii) areas of **increased fire resistance of forest stands** that perform important **ecosystem services** (es. biodiversity, production, direct protection) so that after the fire has passed, severity is reduced, ground cover ensured, and recovery times faster.

At the stand scale, the **question that arises is to what extent do fire prevention requirements conflict with habitat conservation requirements** (e.g. specific diversity, age classes, presence of standing and ground deadwood of different sizes). What texture and vertical structure are useful to **mitigate fire behaviour**? Does this structure guarantee the conservation of the **habitat characteristics of interest**? Which **size classes of deadwood** contribute to the flammability of the fuel complex and which to the conservation of biodiversity?

The **territorial scale** deepens the theme of **integrating the strategic objectives** of biodiversity conservation and the protection of Natura 2000 habitats into fire prevention **planning tools**. These spatial plans spatially distribute, and size **preventive infrastructures** based on an **analysis of the risk** and **expected behaviour of large fires**, i.e. the **preferential trajectories** that these fires may follow under given vegetation, orographic and meteorological conditions.

At this scale of analysis, the **question is how to integrate biodiversity conservation into the strategic planning of preventive infrastructures**. What aspects of biodiversity conservation condition the planner's **choices** of where to locate preventive infrastructures? What are the **possible trade-offs** between biodiversity conservation and other criteria of strategic preventive planning, primarily **public protection**? What percentage of treatment should be devoted to the protection of biodiversity conservation sites, such as Natura 2000 sites, protected habitats and **core areas** and **islands of senescence**? Under what circumstances do I choose to plan the infrastructure **outside or inside** Natura 2000 sites?

The answer to these questions must be addressed on a case-by-case basis, according to the territorial characteristics in terms of **fire regime**, **risks** to the population, **types of habitats** present, and the technical capabilities of the competent bodies. **Deliverable D3.2** elaborates on the two scales of analysis using as case studies the habitats and Natura 2000 sites identified by the **GoProForMed** project with reference to: i) habitats **9260 - Castanea sativa woodlands** and **9530 - (sub)Mediterranean endemic black pine forests**; ii) Special Conservation Zones **IT5180011 - Mountain pastures and shrublands of Pratomagno** (hereafter Pratomagno) and **ES5140008 - Muntanyes de Prades** (hereafter Prades).

D3.2 refers to the **structural elements** for the conservation of habitats in Natura 2000 sites defined by Life GoproForMed and described in **Table 1** and uses the **"Biodiversity Islands intervention protocol" (WP3 - Tools for CNF management)** as a starting point for reasoning on the integration of fire prevention in silvicultural measures for the conservation of target habitats.

Table 1 - Description of structural elements for biodiversity conservation.

Structural element	Abbr.	Description
Core Area	CA	Area characterised by a high functional and qualitative value for the conservation of biodiversity. This value is considered in relative terms regarding the target forest stand. The Core Area represents an element that will be permanently maintained and constitutes a node in the ecological network. The function of the Core Area is as a source of dispersal of mobile species. No interventions are planned within the CA for the biodiversity function.
Islands of Biodiversity	IB	Small reserves (at least 1 ha in size) with the main objective of conserving the deadwood and related biodiversity, starting with saproxylic insects. The structural complexity of the IBs and thus their value for biodiversity is defined based on elements such as quantity and quality of the deadwood, presence and abundance of dendromicrohabitats, presence of open areas and stand structure. This classification makes it possible to identify two distinct types of IB: Conservative IB and Improved IB. For the former, since the structural complexity is already adequate for the required function, no interventions are envisaged. For the latter (Improved IB), the current structural complexity is considered inadequate, so interventions are proposed aimed at increasing this aspect. Operational intervention methods, aimed at increasing structural complexity for biodiversity purposes, are proposed in the project document "Biodiversity Islands intervention protocol" (WP3 - Tools for CNF management).
Edge Area	EA	Area occupied by the target habitat, external and contiguous to the Core Area, and coinciding with the area indicated by the Project. In this area it is foreseen that Biodiversity Islands (IB), which correspond to 5% of the Edge Area, will be placed and implemented, and habitat trees (generally 10 for each IB) will be identified. On the remaining area of the Edge Area, forest management according to the close-to-nature silviculture approach is proposed.
Tree habitat	HT	Connecting elements between Islands of Biodiversity (IB) and Core Areas (CA) that facilitate the movement of less mobile species (especially invertebrates). For the purposes of the project, the trees within the stand with at least one microhabitat (TreM) listed as 'priority' or, alternatively, at least 3 different microhabitats are classified as HT. For these elements too, punctual interventions are envisaged, where necessary, to foster their development. These interventions coincide with what is proposed under 'OB3. Promoting the presence of habitat trees' of the project document 'Biodiversity Islands intervention protocol' (WP3 - Tools for CNF management) and are to be contextualised in the active forest management activities of the entire Edge Area (EA).

1.1. Stand-scale fire prevention

1.1.1. Types of preventive infrastructures

Two types of preventive infrastructure are considered in deliverable D3.2: (i) shaded fuelbreaks to support active firefighting; (ii) self-resistance zones for forest stands.

Shaded fuelbreaks: linear infrastructures aimed at reducing the intensity of the flame front by a sufficient space to increase the effectiveness and safety of active firefighting. Their construction and maintenance are designed based on an analysis of the expected behaviour of the fire entering the fuelbreak and possible active firefighting strategies. These infrastructures are made up of strips of varying size, placed upstream and downstream of the existing road system, in which the horizontal and vertical continuity of the vegetation is reduced, without altering the general soil protection function and still guaranteeing the provision of other important ecosystem services. Breaks are created in forest stands (both coniferous and deciduous), shrub formations and grasslands. Fuelbreaks must always be reachable by firefighting vehicles via an entry and exit route and be equipped with water points. However, they may have different dimensional characteristics depending on the type of vegetation present and the expected behaviour of the flame front entering the infrastructure.

Self-resistance interventions: interventions aimed at improving the resistance and resilience of forests to fire disturbance in forest areas that perform fundamental functions (e.g. direct protection from falling rocks). In this case the infrastructure does not serve to facilitate active fire-fighting activities, but to guarantee a persistence percentage of the forest cover even in the case of severe fires from which the post-fire succession dynamics may restart more quickly (e.g. due to the presence of seed-bearers trees). Depending on the stationary conditions and the expected behaviour of the fire front, silvicultural prescriptions may provide for different silvicultural treatments (thinnings, preparation cuts, fuelbreaks, gaps or slots cuts, seeding cuts, conversions to high-forest, reforestation and surface fuels management interventions such as deadwood preparation, prescribed fire, prescribed grazing). The types of treatment vary according to the expected behaviour of the flame front, the type of stand and its function.

1.1.2. Integration of habitat conservation objectives into silvicultural prescriptions for fire prevention

Deliverable D3.2 starts from the silvicultural prescriptions proposed in the project document "**Biodiversity Islands intervention protocol**" (**WP3 - Tools for CNF management**) and has evaluated which silvicultural practices proposed in the IBs and for the HTs are **compatible with active firefighting activities** in the case of the presence of a fuelbreak, or to what extent **they improve the self-resistance** of forest **stands** to fire disturbance, and which, on the other hand, are to be considered in partial or total contrast with the functions of these two infrastructures. The assessment was structured into intervention objectives, as proposed in the document "Biodiversity Islands intervention protocol". To make the understanding of the analysis more complete, an introduction is given for each silvicultural objective, which derives from the summary of the document itself.

The coherence between silvicultural practices for habitat conservation and fire prevention principles is evaluated only for the IBs and HTs most exposed to fire danger on a territorial scale. In these situations, the adoption of silvicultural practices aimed at habitat conservation must not create favourable conditions for the propagation of a potential fire with severe effects (e.g. widespread stand mortality, organic soil combustion, exposure of fire operators to the extreme behaviour of the flame front). On the other hand, some silvicultural practices aimed at conserving and increasing biodiversity may have **positive effects on reducing flammability and on the resistance to fire disturbance** of individuals or of the entire stand.

The extension of IBs is another element to take into consideration. For IBs characterised by small areas (1 to 5 ha) it will be necessary to assess the consistency between silvicultural practices for biodiversity and fire

prevention for the entire area subjected to silvicultural interventions. For IBs with larger areas (> 5 ha), the coherence between silvicultural interventions and fire hazard will have to be assessed only in the portions of the IB from which fire is most likely to enter, and for a perimeter intervention band with a variable depth towards the interior of the IB depending on the expected behaviour of the flame front (flame length) and the habitat analysed. For HT, the assessment is to be carried out on all the individuals located in the portion of the Edge Area classified as having the greatest fire hazard by landscape scale analysis.

1.2. Landscape-scale fire prevention

1.2.1. Strategic planning of prevention on a territorial scale

The strategic planning of preventive infrastructures has the objective of reducing fire **hazard** (i.e. potential behaviour in terms of flame length and linear intensity) in areas where **potential damage** is expected, i.e. areas that are **vulnerable** and **exposed** to fire danger. The hazard is the probability that an intense fire will spread in an area of the analysed territory. In D3.2, hazard was analysed with **decision support tools** based on fire propagation models (Finney 2004). The exposure consists of the presence and extension of urban-rural interface areas and ecosystem services provided by forest stands. The following ecosystem services were considered in this paper: **conservation of biodiversity, soil protection, and biomass-carbon stock production**. To understand how to mitigate fire hazards in exposed areas it is possible to plan and implement preventive infrastructures on the territory as defined in **section 1.1**. However, the **resources available** for building infrastructure are always **limited**. In the two pilot Natura 2000 areas analysed, i.e. the territories of **Pratomagno in Tuscany-Italy** and **Prades in Catalonia-Spain**, it was decided to maintain the level of investment in preventive infrastructures reported in the **respective territorial scale fire prevention plans**, corresponding to **1% of the total burnable area**. Strategic prevention planning consists of identifying a potential treatable area greater than 1% and then deciding where to distribute the 1% according to the priority objectives to be protected. In deliverable D3.2 the choice of where to plan the infrastructure, i.e. the spatial location and sizing of the areas to be treated, is made by adopting an **optimisation algorithm** that identifies where to locate the minimum area to be treated as a function of the expected reduction in the area burned by large fires that may reach exposed areas of interest.

1.2.2. Integration of habitat conservation objectives in fire prevention infrastructure planning

In deliverable D3.2 alternative scenarios of priorities to be protected were hypothesised in order to test a replicable method of assessing trade-offs between: i) **Absence of prevention - PRE**: a scenario in which no preventive infrastructure is foreseen; ii) **Business as usual - BAU**: a strategic planning that does not prioritise biodiversity conservation (i.e. current planning approach found in the two territories analysed); iii) **Biodiversity - BIO**: a planning that prioritises only biodiversity conservation areas as defined by GoProForMed. In this scenario, the spatial distribution of preventive infrastructures has as its main objective the conservation of the CA and IB present in the area. In the **BIO** scenario, the planning of preventive infrastructures to protect CA and IB includes the creation of active green external fuelbreaks and, only in cases where it is necessary for the effectiveness of the fuelbreaks, interventions in the perimeter portions of the CA and IB are to be foreseen; iv) **TRADE-OFF** scenario: a planning that seeks a compromise between BAU and BIO. In this scenario, the method consists of integrating the best planned location for the BAU and BIO scenarios, **keeping 1% of the total treatable area constant**.

2. Fire prevention and biodiversity conservation at the stand scale

2.1. Fire Prevention Guidelines for Habitat 9260

2.1.1. Sensitivity of habitat 9260 to fire disturbance

Flammability: Chestnut forests are a forest category with variable selectivity by fire (i.e. burnt area over burnable area). In the Italian Alps they are one of the forest categories most affected by fire (Valese et al. 2011), while in the Apennine territory the relative burnt areas are smaller. These differences between the two geographical areas are mainly attributable to the climatic regime and not so much to the flammability of the fuel complex. The flammability of chestnut litter is relatively high compared to other broadleaf litter because it is abundant (Ascoli et al. 2020), long-leaved, less degradable than other broadleaf trees, and porous during dry and windy periods. In contrast, the living crown during the vegetative period is not flammable and does not support crown fire. In summer, when chestnut forests are in good condition and have dense canopy, they can form a natural fuelbreak as they have more moisture than in other seasons. In winter, on the other hand, they are more inflammable and exposed to fire disturbance, as the litter is on the ground and there is no cover to limit moisture fluctuations and wind action. Chestnut forests are particularly flammable in the presence of undergrowth with Ericaceae (e.g. *Erica arborea*, *Calluna vulgaris*), ferns, or accumulations of deadwood because of ageing, decay and overturning of stumps.

Adaptations to fire: chestnut trees show low resistance to fire damage especially in the juvenile phase due to the reduced thickness of the bark. However, with increasing age and diameter, the stem acquires characteristics of resistance due mainly to the thickening of the bark, which is more pronounced in the first few meters at the base and provides good protection from surface fire. Chestnut trunks also have a good ability to form scar callus to cover scars due to necrosis of the meristematic tissues, even in the presence of recurrences of fire over time (**Figure 1**). Chestnut trees are sensitive to crown scorching. The ability to recover after a fire is high due to the high capacity for regrowth, which allows this species to quickly rebuild its photosynthetic capacity and ground cover. In the case of diseased chestnut trees with necrosis, fire penetrates their trunk or stumps with long residence times and thus becomes capable of damaging the stump and compromising the ability to regrow.



Figure 1 - Multiple fire scars on a chestnut stem (left); post-fire basal and epicormic shoots in an aged coppice of fire-prone chestnut (right).

2.1.2. Silvicultural prescriptions within IBs and Habitat trees

This section assesses the **consistency between the silvicultural objectives and prescriptions** of the project document "**Biodiversity Islands intervention protocol**" (WP3 - Tools for CNF management) and the **fire prevention principles**. The assessment was structured in intervention objectives (OB1-OB6), as proposed in

the "Biodiversity Islands intervention protocol" document. Particular attention was paid to objective OB1 - Aiming for a structure of maximum theoretical functionality - in order to understand which silvicultural practices, proposed in the IBs according to the application of the H model (Simini et al. 2010, Anfodillo et al. 2013), are to be considered favourable to increasing the self-resistance of stands to fire and which, on the contrary, are to be considered in partial or total contrast with this objective. This evaluation is supplemented by an analysis of potential fire behaviour following different silvicultural intervention scenarios (see paragraph 2.1.3). To make the understanding of the analysis more complete, each silvicultural objective is introduced by a summary of the information contained in the document.

OB1. Aiming for a structure of maximum theoretical functionality

The **H-model** (Simini et al. 2010, Anfodillo et al. 2013) represents an application of the allometric approach to quantify how far the current forest structure deviates from the theoretical maximum functional condition. The model represents a general and universal tool, applicable to all forests ("Biodiversity Islands intervention protocol" - BOX1). Based on this model, it is possible to estimate the diametrical distribution of a stand that can optimise the resources that would be found in a forest with advanced natural characteristics. The interventions implemented by the GoProForMed project aim to orientate the target stands towards a more complex structure, represented by the reference diametrical distribution derived from the H-model for each of the target habitats. To make this criterion more comprehensible and easier to apply, the structure assessment is carried out based on 4 size classes (**Table 2**).

Table 2 - Size classes defined by the H model and reference diameter ranges.

Categories	Saplings	Poles	Large	Very large
Diameter classes (cm)	10-15 (7,5-17,5)	20-35 (17,5-37,5)	40-55 (37,5-57,5)	>60 (> 57,5)

From the comparison between the distribution in reference diameter classes proposed by the H model and the actual distribution observed in the IB stands through structural surveys, it is possible to determine the characteristics of the silvicultural intervention in terms of the number of trees per hectare to be cut or girdled. The intervention foresees releasing all the cut trees into the forest without cutting and removing the brushwood. The H-model developed for Habitat 9260 is as follows:**Table 3**

Table 3 - Potential diametric distribution for Habitat 9260.

Categories	Saplings	Poles	Large	Very large
Diameter classes (cm)	10-15	20-35	40-55	>60
Habitat 9260	32%	42%	13%	13%

The target diametric equilibrium proposed by the H-model in the IBs is achieved with the following interventions that may be consistent or contradictory with fire prevention principles.

Silvicultural intervention: elimination by cutting or girdling of supernumerary trees with respect to the habitat reference H pattern.

Coherence/contrast with fire prevention: this intervention may be in partial or total contrast with fire prevention depending on the characteristics of the woody material obtained from felling and its destination. The release of felled trees on the ground may in fact represent a criticality if this raises the fuel load in the stand significantly (see **paragraph 2.1.3**).

Silvicultural intervention: conservation or facilitation of trees belonging to sub-numerical diametric classes.

Consistency/contrast with fire prevention: this silvicultural indication is to be considered positive for fire prevention purposes whenever it operates in favour of the Large and Very large classes, since it favours the density of trees with more marked individual resistance characteristics (e.g. greater bark thickness). Conversely, when it implies a selection in favour of the lower diameter classes (Poles) to the detriment of the higher ones, the risk may lie in favouring chestnut individuals with thinner bark and more prone to crown scorch if subjected to a surface fire (Massaiu & Tiger 2022).

Silvicultural intervention: selection of individuals larger than one class if the next is subnumeral to the model

Consistency/contrast with fire prevention: the selection of the most diametrically developed individuals within each class of the H model is to be considered a favourable practice for the purposes of prevention because it generally involves the selection of individuals which, due to vigour and/or stationary factors, have a dominant social position with respect to the other individuals of the same diametrical class. This aspect has repercussions on the morphological characteristics of the tree, which is more likely to show more marked individual resistance characteristics. Furthermore, this choice leads the stand to have individuals with higher diameters within it over time.

Silvicultural intervention: creation of favourable conditions for the establishment of regeneration or the development of existing regeneration if the Sapling class is poorly represented.

Consistency/contrast with fire prevention: the relationship between fire prevention and the creation of openings is analysed under objective OB6 (Encourage the presence of open areas and flowering herbaceous and shrub species). The application of practices favouring the development of saplings for the chestnut tree class is to be considered an indifferent practice for fire prevention purposes, since it does not support crown fire for this species. This diametrical class, being characterised by a thinner bark and crowns carried in the lower part of the stem, is more susceptible to crown scorching because of a surface fire and damage to the cambium. In addition, mortality through natural selection on the stumps may lead to the accumulation of smaller diameter ground fuel. Since, however, it is a deficient evolutionary stage, its presence is assumed to be limited and localised in the forest stand.

OB2. Promoting very large trees (VLTs) (diameters > 57.5 cm)

Large trees play a wide range of ecological roles, influencing the hydrological regime, nutrient cycling and numerous other ecosystem processes (Lindenmayer & Laurance 2016). They also play a key role by providing habitats for many tree and animal species due to their microhabitats, size and large canopies, which provide shelter, food and breeding sites for many species, particularly epiphytic species and cavity-nesting birds and

bats (Mollet et al. 2013; Hofmeister et al. 2015), thus contributing to forest biodiversity (Emberger et al. 2016). The following interventions may be consistent or inconsistent with fire prevention principles in IBs.

Silvicultural intervention: preserving existing VLT trees.

Consistency/contrast with fire prevention: the release of trees characterised by considerable diametrical development (diameters > 57.5 cm) is to be considered favourable to increasing the stand's resistance and resilience to fire disturbance. Trees with a large diameter are characterised by functional traits that increase their resistance to fire such as bark thickness and crown base height, which tend to increase with the age and vigour of the tree. In addition, the root system deepens as the tree develops over time and becomes more resistant to the residence of the flame front than a shallow root system (Massiau & Gaulier 1999).

Silvicultural intervention: identifying candidate trees to encourage their growth in younger stands through extensive selective thinning, declined according to more specific objectives

Consistency/contrast with fire prevention (1- in the "Poles" stage, candidates with good mechanical stability ($H/DBH < 80$) are to be favoured): the search for trees with a favourable ratio of development between height and diameter is to be considered positive for fire prevention in several respects. Trees that are more stable are trees that are less likely to be subject to the phenomenon of crashing to the ground or truncation of the stem, thus reducing the probability of an undesirable accumulation of deadwood on the ground or, in the case of partial toppling, creation of an undesirable fuel ladder between the lower and upper layers of the forest stand. Mechanically stable trees can be useful stand structural elements for silvicultural prevention interventions that may include the creation of openings (gaps) aimed at favouring the dissipation of fire heat and a change in fire dynamics. In fact, stable trees are excellent structural elements to select as the edge of the slots: their partial isolation does not preclude their mechanical stability, guaranteeing the shape and size of the opening created over time.

Consistency/contrast with fire prevention (2- in the "Poles" stage, candidates with good crown depth (1/3 of the height) are to be favoured): this species is not subject to crown fires, so the presence of branches even in the lower-middle portion of the stem is not a critical factor for fire propagation

Consistency/contrast with fire prevention (3- in the "Poles" stage candidates with a developed and symmetrical foliage are to be favoured): the search for trees with a harmonious development of the foliage is to be considered a favourable aspect for fire prevention in several respects. Trees with such characteristics are more stable when subjected to stresses such as wind or snow load with a consequent lower probability of being subjected to the phenomenon of crashing to the ground or truncation of the stem and the consequent undesired accumulation of deadwood on the ground or, in the case of partial overturning, creation of an undesired combustible scale between the lower and upper layers of the forest stand. In addition, trees with balanced crowns represent favourable structural elements if intervention is to be carried out to achieve structural irregularity also for fire prevention purposes, such as, for example, opening slots or gaps.

Silvicultural intervention: selecting a certain number of trees to promote their growth in stands at a more advanced developmental stage through a tree silviculture approach, declined according to more specific objectives.

Consistency/contrast with fire prevention (1- in the "Large category" stage, candidates with a larger diameter within the stage (37.5-57.5 cm)): the search for candidate trees in the higher diametrical classes is to be considered favourable for the purposes of fire prevention because trees with a high diametrical development are generally characterised by having morphological elements favourable to their resistance to the passage of fire, such as the thickness of the bark, which tends to increase with the age and vigour of the tree (Massiau

& Gaulier 1999) and the root system, which deepens as the tree develops over time and becomes more resistant than a shallow root system (Massiau & Gaulier 1999).

Consistency/contrast with fire prevention (2- favouring candidates with effective direct competition): the application of silvicultural intervention that operates with the aim of reducing direct competition on a tree implies a reduction in direct contact between canopies, an aspect to be considered not particularly relevant to the fire dynamics of this species, since it is not affected by crown fires. The creation of an irregularity in the canopy cover is however to be considered a favourable aspect with respect to fire dynamics, allowing greater dissipation of fire heat than a situation of full and continuous canopy cover.

Silvicultural intervention: to select, when group structuring is present, a set of neighbouring trees by carrying out an intervention in favour of the whole group (therefore to be treated as a single candidate).

Consistency/contrast with fire prevention: group structuring within this species is to be defined at the scale of releasing several stumps rather than individual trees, given the predominantly coppice origin and management of the stands. The release of several closely spaced stumps, especially in the case of aged coppices, may require thinning on the stump of dead shoots and decaying trees if the dynamics of shoot selection and mortality within the groups may give rise to an unwanted accumulation of fuel.

Silvicultural intervention: select native species that are less represented in the stand if they can develop as large tree individuals.

Coherence/contrast with fire prevention: the release of species other than the main species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific richness is a guarantee of greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-disturbance reaction capacity, such as budding capacity or seed production capacity. Within the chestnut belt of vegetation, poplars, willows and birches are species to be favoured in this sense due to their ability to generate numerous and vigorous shoots.

Silvicultural intervention: select native species less represented in the stand located in particular positions (e.g. near openings or particular soil conditions).

Consistency/contrast with fire prevention: the release of species other than the main species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific richness is a guarantee of a greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-disturbance reaction capacity such as budding capacity or seed production capacity. Their release in particular IB stationary situations also enhances the development potential of minority species in particular local conditions in favour of heterogeneity and richness. The localisation of sporadic species in conditions other than the prevailing stand condition can also be an element in diversifying fire behaviour.

OB3. Fostering the presence of habitat trees

In the context of the project, a Habitat Tree (HT) is defined as "a standing living tree that, in its current state, falls into these situations:

- at least one dendromicrohabitat (TreM) on the list of 'priority' dendromicrohabitats;
- at least one dendromicrohabitat (TreM) that appears to be less frequent within the site;
- at least 3 dendromicrohabitats (TreM)."

Habitat trees are considered of primary importance for forest biodiversity, as they provide ecological niches (tree microhabitats) for sometimes highly specialised forest flora and fauna for at least part of their lives and (Bütler et al. 2013; Bütler et al. 2016; Directora-te-General for Environment, 2023). The proper identification, protection and management of these trees is essential to preserve the ecological function and structural complexity of forests in the long term. The following interventions implemented may be consistent or contrary to the principles of fire prevention in IBs.

Silvicultural intervention: ensure greater longevity of the tree with dendromicrohabitat through selective thinning in its favour that reduces direct competition from trees belonging to the dominant or co-dominant plane allowing more light to reach the crown plane

Consistency/contrast with fire prevention: the application of a silvicultural intervention that operates with the aim of reducing direct competition on a tree implies a reduction in direct contact between canopies, an aspect to be considered not particularly relevant in the fire dynamics of this species, since it is not affected by crown fires. The creation of an irregularity in the canopy cover is however to be considered a favourable aspect with respect to fire dynamics, allowing greater dissipation of fire heat than a situation of full and continuous canopy cover.

Silvicultural intervention: enrich the structural complexity of the stand in the vicinity of their presence by strongly reducing the forest density in the contiguity of TreMs hosting birds or bats, to make these trees more favoured for these wildlife species.

Coherence/contrast with fire prevention: this practice may become a critical element for fire prevention if the reduction of tree density in the vicinity of the TreM tree involves the cutting of the trees and their release onto the fall bed. This accumulation of deadwood in the vicinity of the candidate may represent a critical potential fuel accumulation for the fire to remain in the vicinity of the candidate's stem and the heat radiated towards the canopy above.

Silvicultural intervention: include in the list of TreMs also standards from previous coppice management even if they lack dendromicrohabitat and encourage their viability and permanence with silvicultural interventions implemented in their favour as they are excellent potential TreM trees.

Consistency/contrast with fire prevention: the selection of standards as candidate trees to become future TreMs is to be considered a favourable practice from the point of view of fire prevention because trees characterised by a development, both diametrically and in height, superior to the prevalence of stand trees are favoured. Such trees are therefore more likely to possess self-resistance characteristics such as thicker bark, deeper root system and more balanced crown development.

OB4. Promoting forest-specific diversity

Tree species composition in forest stands has been shown to be a key determinant of forest-associated biodiversity in several studies (Penone et al. 2019; Ampoorter et al. 2020). Specific diversity ensures a wider variety of fruits, seeds, flowers and foliage available as food sources for wildlife (Emberger et al. 2016). Furthermore, many studies have provided ample evidence that tree-specific diversity in forests can influence key ecosystem processes such as biomass production, nutrient cycling and pest regulation (Cardinale al. 2012; Emberger al. 2016). Finally, there is a positive relationship between specific diversity and resilience; systems that are more diverse in specific composition showing greater resilience to disturbance dynamics (Silva al. 2015). The following interventions implemented can be consistent or contradictory with the principles of fire prevention in IBs.

Silvicultural intervention: encourage greater specific richness by releasing all trees belonging to sporadic species.

Coherence/contrast with fire prevention: the release of sporadic species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific richness is a guarantee of greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-fire reaction capacity, such as budding capacity or seed production capacity.

Silvicultural intervention: encourage growth and development of trees belonging to sporadic species characterised by good vigour by reducing direct competition from other trees with selective thinning.

Consistency/contrast with fire prevention: the application of a silvicultural intervention that operates with the aim of reducing direct competition on a tree implies a reduction in direct contact between canopies, an aspect to be considered not particularly relevant to the fire dynamics of this species, since it is not affected by crown fires. The creation of an irregularity in the canopy cover is however to be considered a favourable aspect with respect to fire dynamics, allowing greater dissipation of fire heat compared to a situation of full and continuous canopy cover

OB5. Fostering a heterogeneous vertical structure

The diversity and development of vertical layers closely influence forest biodiversity, creating different ecological conditions and niches that are preferentially used by different tree and animal species (Puumalainen 2001; Basile et al. 2016; Emberger et al. 2016). The following implemented interventions may be consistent or contrary to the principles of fire prevention in IBs.

Silvicultural intervention: articulate the vertical structure in the context of candidate interventions by thinning from above the direct competitors of the canopy without intervening on the dominated plane.

Consistency/contrast with fire prevention: the application of a silvicultural intervention that operates with the purpose of reducing direct competition on a tree implies a reduction in direct contact between the crowns, an aspect to be considered not particularly relevant to the fire dynamics of this species, since it is not affected by crown fires. The creation of an irregularity in the canopy cover is, however, to be considered a favourable aspect with respect to fire dynamics, allowing greater dissipation of fire heat than a situation of dense and continuous canopy cover. In these formations, the presence of a dominated plane does not represent a critical aspect regarding the fire dynamics (fuel scale), but it may represent a critical element if evaluated as a factor that, in the medium to long term, may give rise to critical ground accumulations of fuel. It is therefore important to assess the spatial distribution and vitality of the dominated floor.

Silvicultural intervention: articulate the vertical structure in the context of interventions in favour of candidates of sporadic species belonging to the dominated plane by applying a thinning intervention that reduces the density for small areas of intervention to create a spatial irregularity of the canopy.

Coherence/contrast with fire prevention: silvicultural interventions that operate by modifying the horizontal structure of the dominated plane, operating in favour of sporadic species, are to be considered favourable for fire prevention since they increase the horizontal structural heterogeneity of the plane itself with a non-uniform spatial criterion, based on the distribution of sporadic species. This may therefore make it possible to reduce the criticalities linked to the widespread and uniform mortality of the dominated plane with the consequent risk of the accumulation of deadwood on the ground over time. The favourable light conditions

created around the tree of sporadic species, allowing a more harmonious development of the foliage, are to be considered, in the long term, a determining factor in the development of a candidate capable of becoming a valuable seed-bearer with a view to a dynamic of recolonisation post fire disturbance.

OB6. Promote the presence of open areas and flowering herbaceous and shrub species.

Open areas in forests increase landscape diversity by influencing the composition and abundance of insect species (De Groot et al. 2016). Forest wildlife species facultatively utilise these gaps for food resources, due to the increased presence of blooms or for reproduction (Chiari et al. 2013; Emberger et al. 2016; Gittings et al. 2006; Hardersen et al. 2012). Large open areas are crucial for increasing biodiversity, while smaller areas are preferable for species conservation (De Groot et al. 2016). The following interventions implemented may be consistent or contrary to fire prevention principles in IBs.

Silvicultural intervention: ensure the presence of open areas with a total area of between 200-400 m²/ha, possibly distributed in two units (this value includes open areas that may already be present).

Consistency/contrast with fire prevention: the presence of open areas without trees is to be considered a favourable aspect for fire prevention as it allows the dynamics of a fire to be modified. For openings of the dimensions proposed, this dynamic is limited to the reduction of heat in the layer occupied by the stand through the upward ascent of hot air, which finds a preferential exit route upwards in the openings.

Silvicultural intervention: favouring the creation of open areas, reducing as far as possible the impact produced by their creation by operating in points of the site with predisposing characteristics e.g. the presence of edges already present, the presence of rocky areas bordering the area of intervention, opening small gaps that will subsequently be enlarged in the direction of favourable light.

Consistency/contrast with fire prevention: the widening of openings starting from favourable situations already present in the stand, such as stable edges produced by trees grown in stands with lower density, rocky areas, ridges or impluviums, is to be considered a favourable practice for fire prevention purposes because, operating from pre-existing structural or morphological conditions, it reduces the risk of generating a condition of mechanical instability in the stand, which may be followed by a sentence of collapse or crashing of the trees with the consequent accumulation of deadwood on the ground.

Silvicultural intervention: create openings in stands with dense, continuous cover by limiting the unit area to 100 m² and combining this cut with thinning in the stand adjacent to the edge to encourage diffuse light to enter the ground.

Consistency/contrast with fire prevention: for the purposes of fire prevention, the creation of these openings in chestnut stands is to be considered an irrelevant practice since the small surface area of the openings produced has no effect on fire dynamics. The thinning proposed on the remaining stand, to favour the entrance of diffuse light, goes in the direction of a structural articulation to be considered always favourable for the purposes of increasing the resistance and resilience of the stands as already indicated in the previously analysed objectives. The effect induced in this sense will depend on the intensity of the thinning and how it is implemented.

Silvicultural intervention: discourage the spread of any allochthonous species that may be present by avoiding creating openings near them so as not to encourage their proliferation by both agamic and gametic regeneration.

Coherence/contrast with fire prevention: for the purposes of the post-fire reconstitution dynamic, favourable to heliophilous pioneer species, the absence or scarcity of seed-bearing trees of allochthonous species is a determining element in the reconstitution of a stand characterised by the species typical of the vegetation strip to which it belongs.

Silvicultural intervention: avoid the creation of openings in very young broadleaved stands to prevent the resprouting of stumps with the production of shoots that will quickly, as they develop, cover the soil preventing the entry of herbaceous species.

Consistency/contrast with fire prevention: the adoption of this practice in chestnut stands is to be considered favourable as it contrasts with the production of fuel accumulations on the ground and litter induced by the dynamics of selection and mortality occurring among young stump shoots.

OB7. Increase the amount of lying and standing dead wood.

It is estimated that between 20 and 40 per cent of forest trees, animals and fungi depend on dead or dying wood in at least one stage of their life cycle (Bauhus et al. 2019; Emberger et al. 2016). Maintaining different qualities of dead wood in terms of tree species, diameter, decay class and type (standing or lying on the ground) has a positive effect on the conservation of saproxylic species communities (Lachat et al. 2013). Furthermore, dead wood is not only recognised as a key element for saproxylic species but is also known for its important function in nutrient release and water retention (Lachat et al. 2013). Regarding the size of dead wood, larger sizes have been identified as essential for the conservation of saproxylic species for several reasons: being more heterogeneous, they provide more ecological niches and microhabitats, which in turn influence saproxylic species diversity (Lachat et al. 2013); size influences the stability of microclimatic conditions and the availability of the resource, as large deadwood decomposes more slowly, remaining available for a longer period, influencing larval development and the development of different stages of decomposition (Gossner et al. 2013; Motta 2020). Standing deadwood is important for bats and birds, which exploit these structural elements for feeding and nesting or roosting (Rigo et al. 2024); moreover, large elements are normally scarce in managed forests, and it becomes essential to preserve them (Gossner et al. 2013; Lachat et al. 2013). For the purposes of the project, the minimum diameter considered is 17.5 cm (Emberger et al. 2016) and the minimum target quantity is 20 m³/ha (Micò et al. 2022). The following interventions implemented may be consistent or contrary to the principles of fire prevention in IBs.

Silvicultural intervention: do not remove the wood produced by tree cutting from the intervention areas.

Consistency/contrast with fire prevention: the total release of wood deadwood that accumulates on the ground following silvicultural intervention must be carefully evaluated both based on the fire risk of the individual IB and on the volume released and its size. To this end, considerations must be based on the quantity, spatial distribution and quality of the deadwood produced by interventions with the objective of reaching the diametric equilibrium proposed by the H model to which reference is made for considerations on the subject.

Silvicultural intervention: to optimise a differentiation, both through cutting and girdling, of dead wood, declined according to more specific parameters.

Consistency/contrast with fire prevention (1- release density parameter): the diversification of the deadwood in terms of space (set of close or isolated trees) is to be evaluated for fire risk purposes based on the

diametrical development of the trees, i.e. the type of fuel that is released on the ground. In fact, the production of deadwood elements of medium-high diameter does not represent a critical point for fire prevention purposes, so any accumulation of such elements does not represent a critical point. Greater attention should be paid to the management of brushwood.

Consistency/contrast with fire prevention (2- light exposure parameter): the release of fuel under different light conditions is to be considered a favourable factor for fire prevention, since different light conditions induce a different degree of moisture in the ground wood and thus a different degree of flammability, considering the same diameter.

Consistency/contrast with fire prevention (3-moisture parameter): the release of fuel under different moisture conditions is to be considered a favourable factor for fire prevention since the different conditions induce different degrees of flammability in the wood on the ground, considering the same diameter.

Coherence/contrast with fire prevention (4- parameter spatiality): a spatially uniformly distributed release of the deadwood on the ground is, for the purposes of fire prevention, a critical issue as it creates a prerequisite for the continuity of the fuel and thus the potential flame front.

Consistency/contrast with fire prevention (5- parameter typology): for the purpose of the release typology, it becomes relevant to assess, for logs on the ground, the diameter of the accumulated elements, while for standing dead trees this aspect is not relevant.

Silvicultural intervention: applying the girdling technique, declined according to more specific objectives

Coherence/contrast with fire prevention (1- favouring the gradual lightening of the crown of a candidate tree causing the gradual death of the direct competitor avoiding a sudden isolation with consequent stability problems): the implementation of this practice does not represent a criticality for chestnut forests since for these formations there is no problem of crown fire dynamics and therefore the presence of a dead crown near a candidate is not to be considered a criticality.

Consistency/contrast with fire prevention (2- avoid damage to a candidate tree by felling the competing tree located nearby): the implementation of this practice does not represent a critical issue for chestnut forests since the problem of crown fire dynamics does not exist for these formations.

Consistency/contrast with fire prevention (3- favouring the decay of large senescent trees): the creation of standing dead trees by means of the girdling technique can be a critical element if these trees, once dead, can become critical factors for fire, favouring its propagation. A senescent or dead large individual may present cavities favourable to combustion due to the presence of litter or decomposed wood. In such situations, prolonged residence of the fire may give rise to secondary ignition.

Silvicultural intervention: encourage the differentiation of the type of dead wood by cutting the stumps at a height of 1 metre, so that they can also be anchoring elements of the dead wood produced and placed on the ground in sites with a risk of soil erosion

Consistency/contrast with fire prevention: this practice is to be considered indifferent to fire dynamics since the presence of high cut stumps is not a critical issue with respect to the spread or persistence of a fire in the stand.

Table 4 - Summary table of coherence between silviculture for biodiversity conservation on fire prevention aspects for Habitat 9260

Prescriptions	Habitat 9260	Clarifications
OB1. Aim for a structure of maximum theoretical functionality		
eliminating, through cutting or girdling, the surplus trees compared to the reference H model for the habitat	potential conflict	depending on the intensity of removal and the release of logs to the ground
preserving or favoring those belonging to underrepresented diameter classes	potential conflict	if implemented at the expense of Large and Very Large trees
selecting individuals of a larger size class if the next class is underrepresented compared to the model	favorable	
favoring the creation of conditions conducive to the establishment of regeneration or the development of existing regeneration if the "saplings" class is poorly represented	indifferent	
OB2. Promote the presence of very large trees (VLT) (diam. >57.5 cm)		
preserve existing VLT trees	favorable	
nominate a certain number of trees to promote their growth in younger stands through extensive selective thinning. In the "Poles" stage, the candidates to be favored are:		
i) with good mechanical stability (H/DBH<80)	favorable	
ii) with good crown depth (1/3 of the height)	indifferent	
iii) with a well-developed and symmetrical crown	favorable	
nominate a certain number of trees to promote their growth in more advanced evolutionary stage stands through a tree-oriented silviculture approach. In the "Large category" stage, the candidates to be favored are:		
i) with a larger diameter within the stage (37.5-57.5 cm)	favorable	
ii) with actual direct competition	favorable	
when a group structuring is present, nominate a set of nearby trees by implementing an intervention that benefits the entire group (thus treating it as a single candidate)	favorable	
nominate underrepresented native species in the stand, provided they can develop into large-sized trees	favorable	
nominate underrepresented native species in the stand located in particular positions (e.g., near openings or specific edaphic conditions)	favorable	
OB3. Encourage the presence of habitat trees		
ensure greater longevity for trees with dendromicrohabitats through selective thinning in their favor to reduce direct competition from trees in the dominant or co-dominant layer, allowing more light to reach the crown level	favorable	depending on the risk of fuel accumulation, potentially critical near the TreM
enrich the structural complexity of the stand near their presence by significantly reducing forest density in proximity to TreM hosting birds or bats, making these trees more favorable for these faunal species	potential conflict	
include in the TreM list the seed trees from previous coppice management, even if they lack dendromicrohabitats, and enhance their vitality and permanence through silvicultural interventions in their favor, as they are excellent potential TreM trees	favorable	
OB4. Promote species diversity in the forest		
increase species richness by retaining all trees belonging to sporadic species	favorable	
promote the growth and development of trees belonging to sporadic species characterized by good vigor by reducing direct competition from other trees through selective thinning	favorable	
OB5. Promote a heterogeneous vertical structure		
structure the vertical composition of the stand by favoring candidate trees through thinning from above, removing direct crown competitors without intervening in the dominated layer	potential conflict	depending on the possible creation of continuous vertical layers capable of forming a critical fuel ladder concerning the most probable fire direction (for pine forests) or an undesirable accumulation of necromass due to sprout mortality (in chestnut groves)
structure the vertical composition by favoring candidates from sporadic species in the dominated layer by applying thinning that reduces density in small intervention areas, thus creating spatial irregularity in the canopy cover	favorable	
OB6. Encourage the presence of open areas and flowering herbaceous and shrub species		
ensure the presence of open areas covering a total surface between 200-400 m ² /ha, preferably distributed in two units (this value includes any pre-existing open areas)	favorable	
promote the creation of open areas while minimizing the impact of their creation by selecting site locations with predisposing characteristics (e.g., presence of existing edges, proximity to rocky areas) and creating small gaps that will later be expanded towards favorable light conditions	favorable	
create openings in stands with dense and continuous cover, limiting the individual surface area to 100 m ² and combining this cut with thinning in the adjacent stand margin to promote the penetration of diffuse light to the ground	indifferent	
discourage the spread of any present non-native species by avoiding the creation of openings near them to prevent their proliferation both vegetatively and sexually	favorable	
avoid creating openings in very young broadleaf stands to prevent sprout regrowth, which would quickly develop and cover the ground, inhibiting the establishment of herbaceous species	favorable	
OB7. Increase the amount of deadwood on the ground and standing		
do not remove the wood produced by cuts from intervention areas	potential conflict	depending on the quantity, distribution, and quality of the necromass produced by the intervention
optimize differentiation, both through cutting and girdling, of deadwood in terms of:		
i) material density (accumulation of trees and individual trees)	potential conflict	depending on the diameter growth of the trees, which determines the type of fuel released to the ground
ii) illumination (in light and in shade)	favorable	
iii) humidity (in valleys or depressions)	favorable	
iv) spatiality (favoring concentration over regular distribution)	favorable	
v) type (standing or on the ground)	favorable	
apply the girdling technique to:		
i) gradually expose the crown of a candidate tree by causing the gradual death of its direct competitor, avoiding sudden isolation that could cause stability issues	favorable	depending on the creation of a favorable condition for crown fire propagation due to the presence of a dead tree standing near a living one
ii) avoid damaging a candidate tree when felling a nearby competing tree	favorable	depending on the creation of a favorable condition for crown fire propagation due to the presence of a dead tree standing near a living one
iii) promote the decline of large-sized senescent trees	indifferent	
promote the differentiation of deadwood types by cutting stumps at a height of 1 meter so they can also serve as anchor points for deadwood placed on the ground in areas at risk of soil erosion	indifferent	

2.1.3. Potential fire behaviour and management scenarios - Chestnut forests - Habitat 9260

To assess the effects of potential fire passage within habitat 9260 under alternative silvicultural management scenarios, simulations were carried out using the Decision Support System (DSS) FOFEM 6.7 (Lutes 2020).

The **first scenario** represents the **baseline** and describes the current situation of stands in habitat 9260 for the project sites. This scenario excludes silvicultural interventions.

The **second scenario** involves the implementation of a silvicultural treatment characterised by the H-model felling at each site containing habitat 9260, resulting in the release of 100% of the individuals and brushwood into the forest. In this scenario, all the felled trees envisaged by the H-model are released into the forest, including branches of all sizes.

The **third scenario** involves the implementation of a silvicultural treatment characterised by the H-model harvesting at each site containing habitat 9260, but with 50% of the individuals and brushwood being released into the forest. In this scenario only 50% of the felled trees are released into the forest.

The **fourth scenario** involves the implementation of a silvicultural treatment characterised by the H-model harvest at each site containing habitat 9260, but with a release of 20% of the individuals and brushwood into the forest. In this scenario only 20% of the felled trees are released into the forest.

Baseline scenario

To carry out the simulation of the baseline scenario in FOFEM, the input data required by the model were prepared, concerning the different fuel components present in the 9260 chestnut forests (**Figure 2**). In particular, the model requires the input of the quantity of biomass expressed as dry weight of the fuel components described in **Table 5**

Table 5 - Description of fuel components required by FOFEM.

Fuel component	Description
Duff	Organic soil including the O horizon.
Litter	Leaves and fine combustible elements (e.g. fruit fragments or bark).
Wood 0-¼ inch	Branches and wood fragments with a diameter (following 'd') < 0.6 cm.
Wood ¼-1 inch	Branches and wood fragments with 0.6 < d < 2.5 cm.
Wood 1-3 inch	Branches and wood fragments with 2.5 < d < 7.6 cm.
Wood 3+ inch	Branches and wood fragments with d > 7.6 cm, divided into 'sound' and 'rotten'.
Herb	Herbaceous layer including Gramineae and flammable grasses.
Shrub	Component with d < 2.5 cm of flammable species in the shrub layer.
Crown	Components of leaves (Foliage) and small branches (Branch) of the crown.

For the purposes of the simulation, the inserted values of *Duff*, *Litter*, *1 h*, *10 h*, *100 h*, *Herb* and *Shrub* were taken from the average values of these components present in the Italian national dataset *Harmonized dataset of surface fuels under Alpine, temperate and Mediterranean conditions in Italy* (Ascoli et al. 2020), while for *1000 h* fuels, which are not present in the dataset, reference was made to the average values of chestnut forests in Tuscany indicated in the latest Italian National Forest Inventory (National Inventory of Forests and Forest Carbon Sinks - INFC). Since within chestnut forests crown fires are very unlikely (see section 2.1.1), the *Foliage* and *Branch* fractions were assigned zero values.

The vegetation type most similar to the European *Castanea Sativa* chestnut forests was chosen the *Cover Type "castanea dentata Forest"* in the North American NVCS classification (*National Vegetation Classification System*). The moisture scenario of the simulation is the *Very Dry* typical of fires under high dehydration conditions.

Figure 2 - Input data entered into the FOFEM 6.7 model for the baseline scenario for all three sites containing habitat 9260 (Muntanya de les Salines, Pratomagno, Sant'Antonio). All load values for each fuel component are in tonnes/acre while the Duff depth is expressed in inches. Note: 1 acre = 0.41 ha; 1 inch = 2.54 cm.

Output baseline scenario

As simulation output data, the indicators of *Fire intensity* (FI expressed in kW/m^2) and *Fuel consumed* (FC expressed in t/ac) were considered. Regarding Figure 3, the parameter of greatest interest is the maximum value reached and the duration of this value over time. In the case of the simulated baseline scenario, the maximum FI achieved is 178 kW/m^2 and is maintained at values above 30 kW/m^2 for approximately 5 minutes.

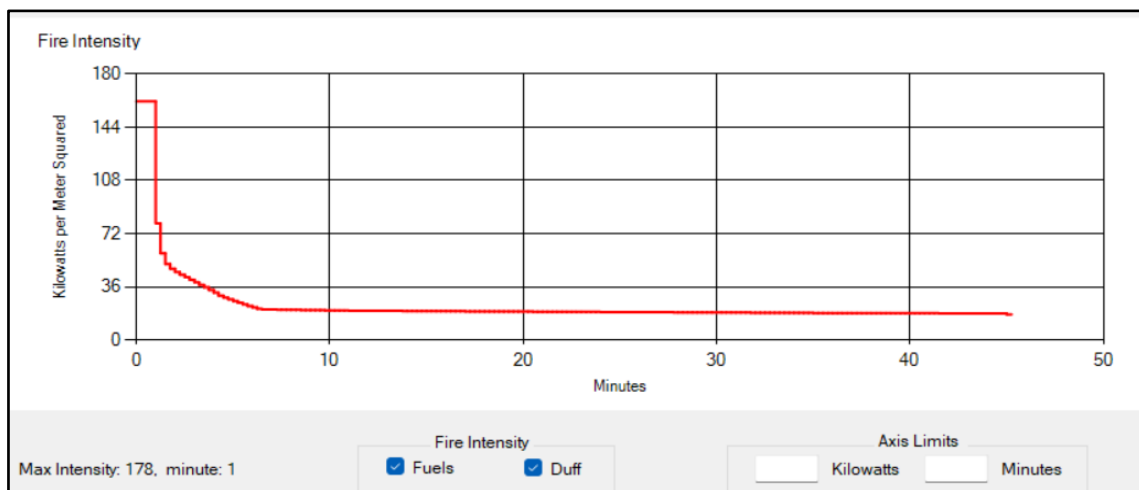


Figure 3 - Fire intensity values (kW/m^2) over time (minutes).

Concerning the fuel consumption in the different components, the results obtained can be seen in Figure 4 and Figure 5. The almost complete loss of fuels 1 h (0-¼ inch), 10 h (¼-1 inch) and 100 h (1-3 inch), a 52% loss of Duff and 80% loss of Litter are shown. Total fuels following the passage of a fire in *Very Dry* conditions are reduced by 58%. It is noteworthy that the model predicts a high % consumption for smaller deadwood fractions while consumption is notably lower in size classes $> 7.5 \text{ cm}$.

Fuel Component Name	FUEL CONSUMPTION TABLE			Percent Reduced (%)	Equation Reference Number	Moist. (%)
	Preburn Load (T/ac)	Consumed Load (T/ac)	Postburn Load (T/ac)			
Litter	1.15 u	0.92	0.23	80.0	998	
Wood (0-1/4 inch)	0.49 u	0.49	0.00	100.0	999	
Wood (1/4-1 inch)	1.48 u	1.48	0.00	100.0	999	6.0
Wood (1-3 inch)	0.63 u	0.62	0.01	98.3	999	
Wood (3+ inch) Sound	1.49 u	0.33	1.16	22.2	999	10.0
3->6	0.37	0.17	0.20	45.2		
6->9	0.37	0.09	0.28	24.3		
9->20	0.37	0.05	0.32	13.3		
20->	0.37	0.02	0.35	5.8		
Wood (3+ inch) Rotten	0.37 u	0.16	0.21	43.4	999	10.0
3->6	0.09	0.07	0.02	80.1		
6->9	0.09	0.05	0.05	50.1		
9->20	0.09	0.03	0.07	29.7		
20->	0.09	0.01	0.08	13.7		
Duff	14.44 u	7.49	6.95	51.9	16	20.0
Herbaceous	0.04 u	0.00	0.04	0.0	222	
Shrubs	0.41 u	0.41	0.00	100.0	234	
Crown foliage	0.00	0.00	0.00	0.0	37	
Crown branchwood	0.00	0.00	0.00	0.0	38	
Total Fuels	20.50	11.90	8.60	58.0		

'u' Preburn Load is User adjusted

Figure 4 - Output table of the consumption of the different fuel components

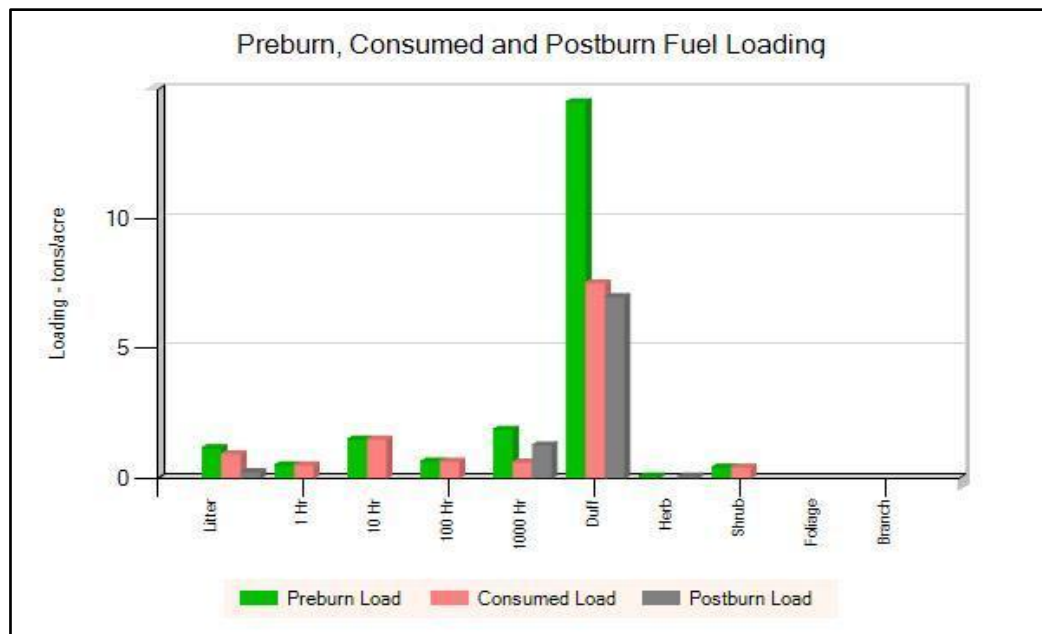


Figure 5 - Output graph of the consumption of the different fuel components. Pre-consumption conditions (green bars), fuel consumed (red bars), fuel not consumed in the combustion process (grey bars).

Post-intervention scenario according to the H model

To assess the impact of silvicultural treatments on surface fuels in the IBs of sites with 9260 chestnut forests, simulations were carried out with different hypotheses for the release of deadwood in the forest following the recovery predicted by the H-model. The simulated scenarios are:

- release of 100 per cent of felled trees and brushwood into the forest;
- release of 50 per cent of felled trees and brushwood into the forest;
- release of 20 per cent of felled trees and brushwood into the forest.

Table 6 shows the values of the different surface fuel components used for the FOFEM simulations in the different intervention scenarios: i.e. 100%, 50% and 20% release of deadwood in the forest. As can be seen from the comparison with the BASELINE scenario (also shown in **Table 6**), in all cases of the post-intervention scenario there are higher values of small deadwood (1 h, 10 h and 100 h fuels), and this is due to the release of a certain percentage of branches into the forest as a result of the interventions.

Table 6 - FOFEM input data in t/ha. Different values according to different percentages of deadwood release in the forest (100%, 50%, 20%).

Site	Treat. Intensity	Duff	Litter	Wood 1h	Wood 10h	Wood 100h	Wood 1000 h	Grass	Shrubs
BASELINE (All sites)	NO INT	35,69	2,84	1,22	3,66	1,55	4,6	0,11	1
Muntanya d.I.S.	100%	35,69	3,28	1,41	4,61	3,13	4,6	0,11	1
	50%	35,69	3,06	1,31	4,13	2,34	4,6	0,11	1
	20%	35,69	2,93	1,26	3,85	1,87	4,6	0,11	1
Pratomagno	100%	35,69	3,15	1,35	4,33	2,66	4,6	0,11	1
	50%	35,69	3	1,28	3,99	2,1	4,6	0,11	1
	20%	35,69	2,9	1,24	3,79	1,77	4,6	0,11	1
Sant'Antonio	100%	35,69	3,14	1,34	4,29	2,6	4,6	0,11	1
	50%	35,69	2,99	1,28	3,97	2,07	4,6	0,11	1
	20%	35,69	2,9	1,24	3,79	1,76	4,6	0,11	1

Output data of post scenarios

As in the case of the BASELINE scenario, the output data considered are always Fire Intensity (kW/m²) and Fuel Consumed (t/ac).

Table 7 shows the maximum FI values found for each of the 3 sites for the different scenarios of woodland deadwood release. With a 100% release into the forest, on average the maximum FI is about 200 kW/m², while a 50% release has slightly lower values of 187 kW/m² and a release of only 20% results in values of 181 kW/m², in line with the baseline scenario (i.e. 178 kW/m²). In the graph at **Figure 6** depending on the greater amount of deadwood present on the ground, higher FI values occur at all the sites considered.

Concerning fuel consumption, **Figure 7**, **Figure 8** and **Figure 9** show the outputs from simulations performed by entering input values of the fuel components in **Table 6**, depending on the different scenarios of the release of brushwood into the forest.

Table 7 - Maximum FI values from FOFEM simulations carried out taking into account the different percentages of deadwood release in the forest.

9260 sites	Treat.	Max Fire Intensity
BASELINE	0%	178
Munt. de les salines	100%	200
	50%	189
	20%	183
Pratomagno	100%	194
	50%	186
	20%	181
Sant'Antonio	100%	193
	50%	186
	20%	180

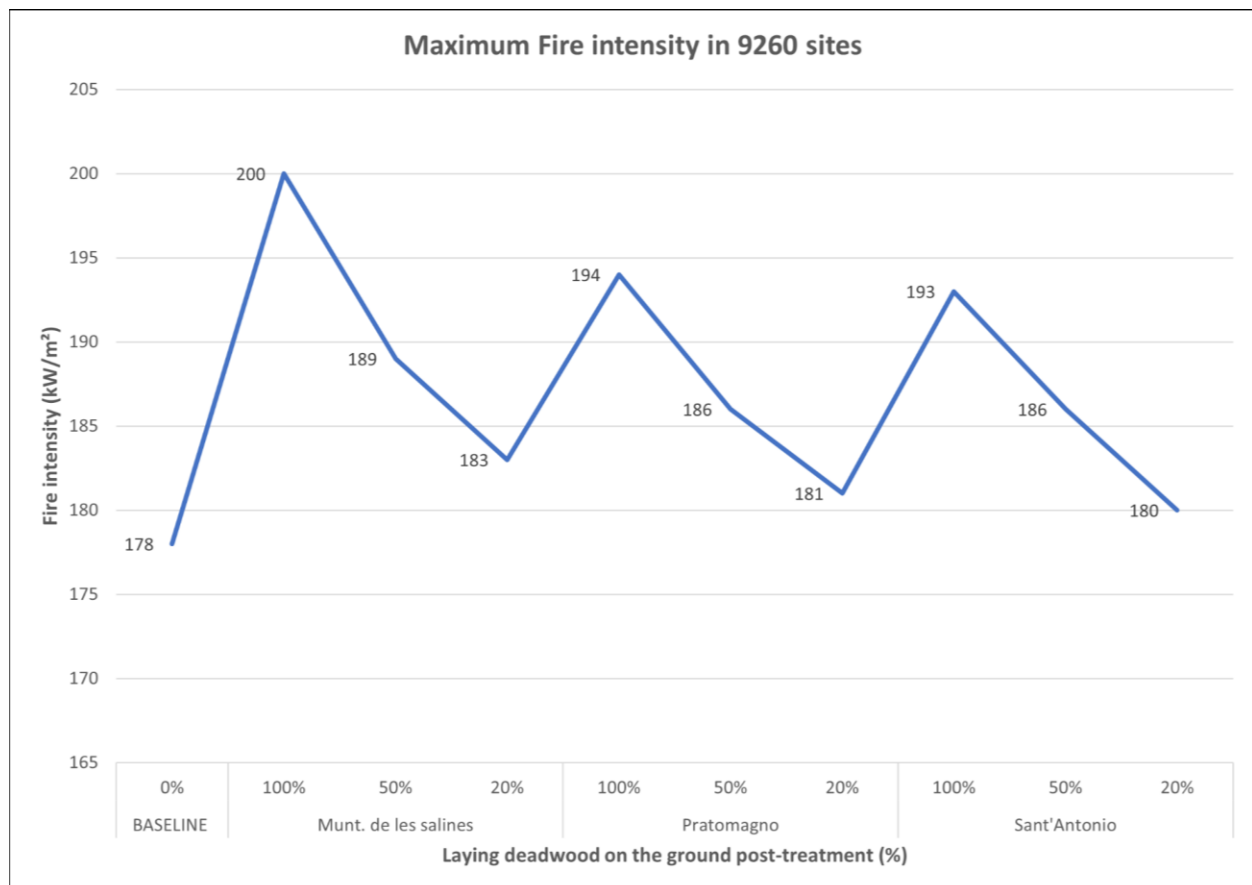


Figure 6 - Graph of Fire Intensity under different post-intervention scenarios at the 3 different sites with habitat 9260.

Fuel Component Name	FUEL CONSUMPTION TABLE				Equation Reference Number	Moist. (%)
	Preburn Load (T/ac)	Consumed Load (T/ac)	Postburn Load (T/ac)	Percent Reduced (%)		
Litter	1.29 u	1.03	0.26	80.0	998	
Wood (0-1/4 inch)	0.55 u	0.55	0.00	100.0	999	
Wood (1/4-1 inch)	1.78 u	1.78	0.00	100.0	999	6.0
Wood (1-3 inch)	1.13 u	1.12	0.01	99.1	999	
Wood (3+ inch) Sound	1.49 u	0.35	1.14	23.3	999	10.0
3->6	0.37	0.18	0.20	47.1		
6->9	0.37	0.10	0.28	25.6		
9->20	0.37	0.05	0.32	14.3		
20->	0.37	0.02	0.35	6.2		
Wood (3+ inch) Rotten	0.37 u	0.17	0.21	44.7	999	10.0
3->6	0.09	0.08	0.02	81.9		
6->9	0.09	0.05	0.04	51.8		
9->20	0.09	0.03	0.06	30.8		
20->	0.09	0.01	0.08	14.2		
Duff	14.44 u	7.40	7.04	51.3	16	20.0
Herbaceous	0.04 u	0.00	0.04	0.0	222	
Shrubs	0.41 u	0.41	0.00	100.0	234	
Crown foliage	0.00	0.00	0.00	0.0	37	
Crown branchwood	0.00	0.00	0.00	0.0	38	
Total Fuels	21.50	12.81	8.69	59.6		
'u' Preburn Load is User adjusted						

Figure 7 - Fuel consumption in scenarios with 100% release of branches into the forest

Fuel Component Name	FUEL CONSUMPTION TABLE				Equation Reference Number	Moist. (%)
	Preburn Load (T/ac)	Consumed Load (T/ac)	Postburn Load (T/ac)	Percent Reduced (%)		
Litter	1.22 u	0.98	0.24	80.0	998	
Wood (0-1/4 inch)	0.52 u	0.52	0.00	100.0	999	
Wood (1/4-1 inch)	1.63 u	1.63	0.00	100.0	999	6.0
Wood (1-3 inch)	0.88 u	0.87	0.01	98.6	999	
Wood (3+ inch) Sound	1.49 u	0.34	1.15	22.7	999	10.0
3->6	0.37	0.17	0.20	46.1		
6->9	0.37	0.09	0.28	25.1		
9->20	0.37	0.05	0.32	13.7		
20->	0.37	0.02	0.35	6.0		
Wood (3+ inch) Rotten	0.37 u	0.16	0.21	44.0	999	10.0
3->6	0.09	0.08	0.02	80.9		
6->9	0.09	0.05	0.05	50.9		
9->20	0.09	0.03	0.06	30.2		
20->	0.09	0.01	0.08	13.9		
Duff	14.44 u	7.45	6.99	51.6	16	20.0
Herbaceous	0.04 u	0.00	0.04	0.0	222	
Shrubs	0.41 u	0.41	0.00	100.0	234	
Crown foliage	0.00	0.00	0.00	0.0	37	
Crown branchwood	0.00	0.00	0.00	0.0	38	
Total Fuels	21.00	12.35	8.65	58.8		
'u' Preburn Load is User adjusted						

Figure 8 - Fuel consumption in scenarios with 50% release of branches in the forest.

Fuel Component Name	FUEL CONSUMPTION TABLE				Equation Reference Number	Moist. (%)
	Preburn Load (T/ac)	Consumed Load (T/ac)	Postburn Load (T/ac)	Percent Reduced (%)		
Litter	1.18 u	0.94	0.24	80.0	998	
Wood (0-1/4 inch)	0.50 u	0.50	0.00	100.0	999	
Wood (1/4-1 inch)	1.54 u	1.54	0.00	100.0	999	6.0
Wood (1-3 inch)	0.73 u	0.72	0.01	98.5	999	
Wood (3+ inch) Sound	1.49 u	0.33	1.15	22.5	999	10.0
3->6	0.37	0.17	0.20	45.7		
6->9	0.37	0.09	0.28	24.8		
9->20	0.37	0.05	0.32	13.6		
20->	0.37	0.02	0.35	5.9		
Wood (3+ inch) Rotten	0.37 u	0.16	0.21	43.7	999	10.0
3->6	0.09	0.07	0.02	80.5		
6->9	0.09	0.05	0.05	50.5		
9->20	0.09	0.03	0.07	30.0		
20->	0.09	0.01	0.08	13.8		
Duff	14.44 u	7.47	6.97	51.7	16	20.0
Herbaceous	0.04 u	0.00	0.04	0.0	222	
Shrubs	0.41 u	0.41	0.00	100.0	234	
Crown foliage	0.00	0.00	0.00	0.0	37	
Crown branchwood	0.00	0.00	0.00	0.0	38	
Total Fuels	20.70	12.08	8.62	58.4		
'u' Preburn Load is User adjusted						

Figure 9 - Fuel consumption in scenarios with 20 per cent release of branches in the forest.

2.2. Self-resistance in Habitat 9260 stands: prescriptions in the areas of intervention outside the CA and IB, perimeter to the IB and on Habitat Trees (HT)

This section describes the criteria for preventive silviculture to be implemented in the infrastructure of self-resistance to fire disturbance in chestnut stands - Habitat 9260 outside the CA and IB, perimeter to the IB. The requirements for fuel management in the vicinity of Habitat Trees (HT) are also described. The summary of the parameters proposed in the chapter is illustrated **Figure 52** and **Figure 53** and in the mind map shown in **Figure 56**.

For CA, preventive silviculture interventions must always be implemented for self-resistance in stands located outside these areas and in the direction of the most probable fire. The depth of the intervention strip must be greater than 70 meters and its width must vary according to the steepness and morphology of the slope.

For the IBs, preventive silviculture interventions for self-resistance are always to be implemented when, in the analysed area, they are those with the highest fire hazard and the greatest size. For IBs that fall in this situation and are classified as "conservative", interventions must be carried out only on the forest stand outside these and in the direction of the most probable fire. The depth of the intervention strip must be greater than 50 meters and its width must vary according to the slope and morphology of the slope. For IBs classified as "improved", intervention must always be envisaged in stands outside these areas (always for a strip > 50 m) and, if deemed functional to the effectiveness of external intervention, internal intervention must also be envisaged, always in the direction of the most probable fire, for a strip 20-30 m deep.

For Habitat Trees located in the portions of the area with the highest fire hazard, it is always necessary to implement preventive silviculture interventions for self-resistance by operating, in the lower part of the canopy layer (fuel management), for a band of at least 5 meters radius from the trunk.

The prescriptions are illustrated by distinguishing between activities affecting stands (**managed as coppice** or **initiated/managed as high forest**) and activities affecting surface fuels.

Coppice management

As part of the application of ordinary coppice management, the self-resistance of the stand should be increased:

- ✓ creating a structure characterised by a spatial distribution of standards preferentially by groups and secondarily by stable isolated trees
- ✓ creating a diametrical structure of the standards capable of maximising diametrical diversification both for the chestnut (if trees with different diameters are available) and for other species, releasing individuals belonging to as many diametrical classes as possible
- ✓ creating a horizontal structure characterised by a distribution of groups as evenly as possible over the area of intervention
- ✓ releasing a residual group canopy cover of between 10 and 25 per cent
- ✓ reducing the fuel load within the groups, when necessary, by removing decaying, sloping, dead (standing and ground) shoots. The removed material must be taken away from the forest or appropriately fragmented and spread on the ground
- ✓ avoiding the release, within the coppices, of flammable species in the vicinity of groups of standards.

High forest/Conversion to High Forest management

As part of the application of ordinary high forest or conversion to high forest management, the stand's self-resistance should be increased:

- ✓ carrying out, depending on the starting structure, variable harvesting interventions in terms of volume/ha, base area/ha and trees/ha to create more structurally articulated forest stands
- ✓ favouring the creation of a forest structure by selecting, from the coppice, two/three best shoots on each stump (according to their development and vigour) with the objective of having approximately 600-800 stems/ha. On young stumps thinning the resprouting of shoots with early thinning and selective thinning
- ✓ favouring, when present, regeneration from seed, avoiding the formation of excessively dense clusters at the most critical points for fire prevention purposes
- ✓ increasing the specific mix by favouring species other than the chestnut tree through selective thinnings of chestnut trees in proximity and direct competition (tree silviculture). If the tree to be favoured has an underdeveloped crown unsuitable for isolation, thinning should be carried out to promote stability by releasing neighbouring co-dominant trees that play a relevant role in stability (e.g. for steep slopes eliminate competitors located upstream and along the contour line and release those downstream)
- ✓ modifying the structure to reduce the quantity and horizontal continuity of fuels in the different fuel layers of the stand (litter and deadwood layer, herbaceous layer, low and high shrub layer, tree crown layer)
- ✓ working towards group structuring of the forest stand by releasing stable trees (chosen from well-formed, vigorous shoots and seedlings), biogroups and stumps
- ✓ favouring an articulated diametrical structure and favouring larger diameters by applying decreasing tree harvesting as the diameter class increases
- ✓ preserving and promoting the development of the native broadleaved tree species in the stand. These species, when having regular and sufficiently deep crowns, must be freed from competition, or must be protected within the groups if this is not the case (by carrying out selective thinning within the group itself).

Management of surface fuels

In addition to interventions on the tree component of the stand, it is desirable to increase the self-resistance of the stands through the management of surface fuels within them. Fuel management can be implemented by applying various techniques:

- ✓ reducing deadwood of all sizes at critical points: impluvium areas, slope changes
- ✓ maintaining a maximum of 20 per cent of the flammable shrubs and bush cover with a maximum height of 2 m, taking care not to leave any ladder fuels. Avoiding the release of flammable species in the vicinity of groups of standards within coppices
- ✓ reducing fine surface fuels (litter, grasses and deadwood with diameters < 2.5 cm) to bring the load below 15 t/ha
- ✓ Manual surface fuel reduction interventions: scrub clearance and reduction of deadwood with a chainsaw. Cut and spread the deadwood adhering as much as possible to the ground avoiding accumulations, especially at the base of stems or downstream from groups of trees
- ✓ where possible, burn cutting residues in piles (volume < 3 m steres)
- ✓ mechanical surface fuel reduction measures: carry out chopping and chipping on slopes < 15% and on sites with good accessibility and no rocky outcrops.

2.3. Fire Prevention Guidelines for Habitat 9530

2.3.1. Habitat sensitivity 9530

Flammability: The black pine, in its adult stages, develops several physiological characteristics for not being susceptible to fire, strategies that work if it is in forest structures without much undergrowth, with discontinuous vertical stratification of vegetation and a more or less open forest cover. The high leaf moisture content allows black pine to withstand a lot of heat, if the buds and twigs, which tolerate higher temperatures than needles, are not severely burnt (Domènech et al. 2018).

Regeneration is a critical phase for black pine forests because the seeds have more restrictive edaphic and environmental requirements than other pines present in the habitat (Aleppo pine or Scots pine). In general, the seeds need to be in contact with mineral soil and, at the same time, a certain degree of moisture and cover to avoid direct sunlight. Therefore, the undergrowth has a complex competitive relationship with the black pine. However, the presence of an adult canopy does not hinder the establishment of a new cohort, especially in mixed structures with denser and thinner stands. Black pine does not participate in the first response after a forest fire, because it needs more pioneer tree and shrub species to recover earlier. This means that during the early stages after a large fire, species such as holm oak, Aleppo pine or even Scots pine dominate the habitat and the black pine reappears years later, in the shadow of their cover.

Adaptations to fire: Black pine individuals show several adaptations to fire that make them resistant in different environmental conditions. A key characteristic is the self-pruning of low branches, and the umbrella-like crown shape carried in the upper part of the trunk, which creates vertical discontinuity between the crowns and the lower vegetation, limiting the spread of fire. In addition, the bark, consisting of large, thick, low-flammable and highly insulating plates, offers effective protection against high temperatures. Deep roots allow the tree access to underground water reserves, increasing its resilience under conditions of heat stress. High leaf moisture helps reduce the risk of combustion, while the buds and meristems are protected by thick scales and compact clumps of needles. Even in the event of partial crown damage, the black pine can regenerate, thus restoring its photosynthetic capacity.

This species is characterised by its longevity, which allows maximum tree development and, thanks to a straight and strong trunk, avoids problems with rot. Seed production is high, and their anemocora dispersal encourages natural regeneration. However, the black pine has some criticalities that limit its ability to recover from recurrent fires. Seed production shows some annual alternation, causing considerable variability in the available seed bank. Furthermore, black pine reproduces late, with the first seed production occurring between 14 and 23 years, hindering regeneration in areas affected by frequent fires. The seeds do not have a dormancy period, and their viability in the soil is limited to a few months. Germination occurs in spring or early summer, but only in favourable moisture conditions. In years of highly variable climate, seeds may not find the necessary conditions to germinate and may not survive long enough to benefit from any environmental improvements.

Reproductive maturity is reached between 40 and 80 years, depending on seasonal conditions. The seeds are not serotinous: they open as they ripen and do not respond to thermal stimuli. The growth of black pine requires a certain amount of cover; consequently, in the event of intense fires that destroy the canopy, the seeds do not compete effectively with other species that are better adapted to direct sunlight on burnt ground. However, after low-intensity fires that leave the canopy intact, black pine has a greater chance of germination and growth (Domènech et al. 2018).

2.3.2. Silvicultural prescriptions within IBs and Habitat trees

This section assesses the **consistency between the silvicultural objectives and prescriptions** of the project document "**Biodiversity Islands intervention protocol**" (WP3 - Tools for CNF management) and the principles of fire prevention. The assessment was carried out by dividing this by intervention objectives (OB1-OB6), as

proposed in the "Biodiversity Islands intervention protocol" document. Particular attention was paid to objective OB1 -Aiming for a structure of maximum theoretical functionality- in order to understand which silvicultural practices, proposed in the IBs according to the application of the **H model** (Simini et al. 2010; Anfodillo et al. 2013), are to be considered favourable to increasing the self-resistance of forest stands to fire and which, on the contrary, are to be considered in partial or total contrast with this objective. This assessment is supplemented by an analysis of potential fire behaviour following different silvicultural intervention scenarios (**see section 2.3.3**).

To make the understanding of the analysis made more complete, each silvicultural objective is introduced by a summary of the information contained in the document.

OB1. Aiming for a structure of maximum theoretical functionality

The H-model (Simini et al. 2010; Anfodillo et al. 2013) represents an application of the allometric approach that makes it possible to quantify how far the current structural condition of the forest deviates from the theoretical maximum functional condition. The model represents a general and universal tool, applicable to all forests ("Biodiversity Islands intervention protocol" - BOX1). Based on this model, it is possible to estimate the diametrical distribution of a stand capable of optimising resources in the same way as a forest with advanced natural characteristics. The measures implemented by the project aim to orient the stand towards a more complex structure, represented by the reference diametric distribution derived from the model for each of the four target habitats. In order to make this criterion more comprehensible and easier to apply, the structure assessment is carried out on the basis of 4 size categories (**Table 8**).

Table 8 - Size classes defined by the H model and reference diameter ranges.

Categories	Saplings	Poles	Large	Very large
Diameter classes (cm)	10-15 (7,5-17,5)	20-35 (17,5-37,5)	40-55 (37,5-57,5)	>60 (> 57,5)

By comparing the reference diametrical distribution obtained from the H Model with the actual distribution of the stands, derived from the characterisation of the Islands of Biodiversity carried out by means of structural surveys, it is possible to determine the characteristics of the intervention in terms of the number of trees per hectare to be cut or girdled.

The application of silvicultural interventions aimed at achieving the diametric balance proposed by the H-model is calibrated according to the following points:

Silvicultural intervention: elimination by cutting or girdling of supernumerary trees based on the habitat reference H pattern.

Consistency/contrast with fire prevention: this intervention may become a partial or total contrast for fire prevention purposes depending on the characteristics of the woody material obtained from felling and its destination. The release of felled trees on the fall bed may in fact represent a criticality if this raises the fuel load in the stand significantly.

Silvicultural intervention: conservation or facilitation of trees belonging to sub-numerical diametric classes.

Consistency/contrast with fire prevention: this silvicultural indication is to be considered, for the purposes of fire prevention, positive whenever operating in favour of the Large and Very large classes because it allows the density of trees with more marked individual resistance characteristics to be favoured, such as, for example, greater bark thickness. For the black pine, selection in favour of the lower diameter classes (Poles) does not represent a critical issue since this species develops thick bark from a young age and tends to raise the crown in the upper portion of the stem due to a marked self-pruning of low branches.

Silvicultural intervention: selection of individuals larger than one class if the next is subnumeral to the model.

Consistency/contrast with fire prevention: the selection of the most diametrically developed individuals within each class of the H model is to be considered a favourable practice for the purposes of prevention because it generally involves the selection of individuals which, due to vigour and/or stationary factors, have a dominant social position with respect to the other individuals of the same diametrical class. This aspect has repercussions on the morphological characteristics of the tree, which is more likely to show more marked individual resistance characteristics. Furthermore, this choice leads the stand to have individuals with higher diameters within it over time.

Silvicultural intervention: creation of favourable conditions for the establishment of regeneration or the development of existing regeneration if the “saplings” class is poorly represented.

Consistency/contrast with fire prevention: the relationship between fire prevention and the creation of openings is analysed under objective OB6 (Encourage the presence of open areas and flowering herbaceous and shrub species). The development of individuals belonging to the Sampling class must be assessed, for fire prevention purposes, according to the morphology of the site and the most probable trajectory of fire spread. In fact, the main problem in this respect derives from the possibility that the structure of the heights of this class may give rise to a vertical continuity of fuel capable of favouring the passage of the fire from the surface to the crowns.

OB2. Promoting very large trees (VLTs) (diam>57.5 cm)

Large trees play an extraordinary range of crucial ecological roles, influencing the hydrological regime, nutrient cycling and numerous other ecosystem processes (Lindenmayer & Laurance 2016). They also play a crucial role for a wide range of tree and animal species due to their microhabitats, size and large canopies, which provide shelter, food and breeding sites for many species, particularly epiphytic species and cavity-nesting birds and bats (Mollet et al. 2013; Hofmeister et al. 2015), thus contributing to forest biodiversity (Emberger et al. 2016)

The interventions implemented by the project aim to

Silvicultural intervention: preserving existing VLT trees

Consistency/contrast with fire prevention: the release of trees characterised by considerable diametrical development (DBH>57.5 cm) is a favourable element from the point of view of increasing the resistance and resilience of stand-scale formations. In fact, trees characterised by a high diametrical development are characterised by having morphological elements that are favourable to their resistance to the passage of fire, such as the thickness of the bark, which tends to increase with the age and vigour of the tree (Massaiu & Gaulier 1999) and the root system which, deepening with the development of the tree over time, becomes more resistant compared to a superficial root system (Massaiu & Gaulier 1999).

Silvicultural intervention: selecting a certain number of trees to encourage their growth in younger stands through extensive selective thinning, declined according to more specific objectives

Consistency/contrast with fire prevention (1- in the "Poles" stage, candidates with good mechanical stability ($H/DBH < 80$) are to be favoured): the search for trees with a favourable ratio of development between height and diameter is to be considered favourable for fire prevention in several respects. Trees that are more stable are less likely to be subject to the phenomenon of crashing to the ground or truncation of the stem, thus reducing the likelihood of an undesired accumulation of deadwood on the ground or, in the case of partial toppling, creating an undesired fuel ladder between the lower and upper layers of the forest stand. Mechanically stable trees can be useful stand structural elements for silvicultural prevention interventions that may include the creation of openings (slots or gaps) aimed at favouring the dissipation of fire heat and a change in dynamics of fire behavior. In fact, stable trees are excellent structural elements to select as the edge of the opening: their partial isolation does not preclude their mechanical stability, guaranteeing the shape and size of the opening created over time.

Consistency/contrast with fire prevention (2- in the "Poles" stage candidates with good crown depth ($1/3$ of the height) are to be favoured): black pine is subject to a crown fire dynamic, therefore the presence of individuals with branches carried even in the lowest part of the stem may represent a criticality for the propagation of fire from the lower to the upper layers of the stand. The search for candidate trees with canopies deeper than $1/3$ of the stem is therefore to be considered contrary to fire prevention within the IoS at greater fire risk.

Consistency/contrast with fire prevention (3- in the "Poles" stage candidates with a developed and symmetrical crown are to be favoured): the search for trees with a harmonious development of the foliage is to be considered a favourable aspect for fire prevention in several respects. Trees with such characteristics are more stable when subjected to stresses such as wind or snow load, with the consequent lower probability of being subject to the phenomenon of crashing to the ground or truncation of the stem and the consequent undesirable accumulation of deadwood on the ground or, in the case of partial overturning, the creation of an undesirable fuel ladder between the lower and upper layers of the forest stand. In addition, trees with balanced crowns represent favourable structural elements if work is to be carried out to achieve structural irregularity also for fire prevention purposes, such as the opening of slots or gaps.

Silvicultural intervention: selecting a certain number of trees to promote their growth in stands at an advanced evolutionary stage through tree silviculture, declined according to several objectives.

Consistency/contrast with fire prevention (1- in the "Large category" stage, candidates with a larger diameter in the 37.5-57.5 cm): the search for candidate trees in the larger diameter classes is to be considered favourable for the purposes of fire prevention since trees with a large diameter are generally characterised as possessing morphological elements favourable to their resistance to the passage of fire, such as the thickness of the bark, which tends to increase with the age and vigour of the tree (Massaiu & Gaulier 1999) and the root system which, deepening with the development of the tree over time, becomes more resistant compared to a shallow root system (Massaiu & Gaulier 1999).

Consistency/contrast with fire prevention (2- favouring candidates with effective direct competition): the application of a silvicultural intervention with the aim of reducing direct competition on a tree implies a reduction in direct contact between canopies, a relevant aspect in crown fire dynamics. The creation of an irregularity in the canopy cover is however to be considered a favourable aspect with respect to fire dynamics, allowing greater dissipation of fire heat compared to a situation of full and continuous canopy cover.

Silvicultural intervention: to nominate, when group structuring is present, a set of neighbouring trees by carrying out an intervention in favour of the whole group (therefore to be treated as a single candidate).

Consistency/contrast with fire prevention: structuring by groups can represent an effective structuring of the conifer stand capable of inducing greater structural articulation, both vertically and horizontally. A necessary precaution in defining the groups is however to avoid the release of trees whose differentiation in height class may represent a criticality in terms of vertical continuity of the fuel.

Silvicultural intervention: select native species that are less represented in the stand as long as they are able to develop as large tree individuals.

Coherence/contrast with fire prevention: the release of species other than the main species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific richness is a guarantee of greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-fire reaction capacity, such as budding capacity or seed production capacity.

Silvicultural intervention: select native species less represented in the stand located in peculiar positions (e.g. near openings or particular soil conditions).

Consistency/contrast with fire prevention: the release of species other than the main species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific richness is a guarantee of a greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-disturbance reaction capacity such as budding capacity or seed production capacity. Their release in peculiar IB stationary situations also enhances the development potential of minority species in local conditions in favour of heterogeneity and richness. The localisation of sporadic species in conditions other than the prevailing stand condition can also be an element in diversifying fire behaviour.

OB3. Encouraging the presence of habitat trees

In the context of the project, a Habitat Tree (HT) is defined as "a standing living tree that, in its current state, falls into these situations:

- at least one dendromicrohabitat (TreM) on the 'priority' dendromicrohabitat list
- at least one dendromicrohabitat (TreM) that is less frequent within the site
- at least 3 dendromicrohabitats (TreM)

Habitat trees are considered of primary importance for forest biodiversity, as they provide ecological niches (tree microhabitats) for sometimes highly specialised forest flora and fauna for at least part of their lives and (Bütler et al. 2013; Bütler et al. 2016; Directora-te-General for Environment 2023). The proper identification, protection and management of these trees is essential to preserve the ecological function and structural complexity of forests in the long term. The interventions implemented by the project aim to:

Silvicultural intervention: ensure greater longevity of the tree with dendromicrohabitat through selective thinning in its favour that reduces direct competition from trees belonging to the dominant or co-dominant plane allowing more light to reach the crown plane

Consistency/contrast with fire prevention: the application of a silvicultural intervention that operates with the aim of reducing direct competition to a tree implies a reduction in direct contact between canopies, an aspect to be considered relevant in canopy fire dynamics.

Silvicultural intervention: enrich the structural complexity of the stand in the vicinity of their presence by strongly reducing the forest density in the contiguity of TreMs hosting birds or bats, to make these trees more favoured for these wildlife species.

Consistency/contrast with fire prevention: this practice may become a critical element for fire prevention if the reduction of tree density in the vicinity of the TreM tree involves the felling of the trees and their release onto the fall bed. This accumulation of deadwood in the vicinity of the candidate can represent a critical potential fuel accumulation in terms of the permanence of fire in the vicinity of the candidate's stem and the heat radiated towards the canopy above. Furthermore, this accumulation may give rise to an undesirable fuel ladder, capable of spreading the fire from the lower levels of the stand to the canopy.

Silvicultural intervention: include in the list of TreMs also standards from previous coppice management even if they lack dendromicrohabitat and encourage their viability and permanence with silvicultural interventions implemented in their favour as they are excellent potential TreM trees.

Consistency/contrast with fire prevention: in pine forests the presence of an individual with diametric development above the stand average is often to be attributed to a release of the individual under previous active management, for multiple reasons. By virtue of their diametrical development and bearing, the proposed practice (selection as a candidate even though lacking dendromicrohabitat) is to be considered favourable for fire prevention purposes due to the fire resistance characteristics developed over time. The only attention to be paid in this regard is the possibility that, correlated to age, there may be elements that are not favourable to its preservation such as resin flows capable of conducting the flame from the ground to the foliage.

OB4. Promoting forest-specific diversity

Tree species composition in forest stands has been shown to be a key determinant of forest-associated biodiversity in several studies (Penone et al. 2019; Ampoorter et al. 2020). Specific diversity ensures a wider variety of fruits, seeds, flowers and foliage available as food sources for wildlife (Emberger et al. 2016). Furthermore, many studies have provided ample evidence that tree-specific diversity in forests can influence key ecosystem processes such as biomass production, nutrient cycling and pest regulation (Cardinale al. 2012; Emberger al. 2016). Finally, there is a positive relationship between specific diversity and resilience, with systems that are more diverse in specific composition showing greater resilience with respect to disturbance dynamics (Silva al. 2015). The following interventions implemented can be consistent or contradictory with the principles of fire prevention in IBs.

Silvicultural intervention: encourage greater specific richness by releasing all trees belonging to sporadic species.

Coherence/contrast with fire prevention: the release of sporadic species is always to be considered a positive aspect from the point of view of increasing the self-resistance of stands, since a greater specific enrichment is a guarantee of a greater stand differentiation against fire, both in terms of resistance capacity and in terms of post-disturbance reaction capacity such as budding capacity or seed production capacity. Within pine formations, specific enrichment in favour of broadleaves is always to be sought.

Silvicultural intervention: encourage growth and development of trees belonging to sporadic species characterised by good vigour by reducing direct competition from other trees with selective thinning.

Coherence/contrast with fire prevention: the application of a silvicultural intervention that operates with the aim of reducing direct competition between trees implies a reduction in direct contact between crowns, an aspect to be considered relevant in crown fire dynamics, especially if the sporadic species is also a conifer. Since in pine formations specific enrichment in favour of broadleaves is always to be sought, the proposed practice may favour the development of trees with deeper crowns, a fundamental premise for becoming adequate seed-bearing trees.

OB5. Fostering a heterogeneous vertical structure

The diversity and development of vertical layers closely influence forest biodiversity, creating different ecological conditions and niches that are preferentially used by different tree and animal species (Puumalainen 2001; Basile et al. 2016; Emberger et al. 2016). The following implemented interventions may be consistent or contrary to the principles of fire prevention in IBs.

Silvicultural intervention: articulate the vertical structure in the context of candidate trees interventions by thinning from above the direct competitors of the canopy without intervening on the dominated layer.

Consistency/contrast with fire prevention: the application of a silvicultural intervention that operates with the aim of reducing direct competition on a tree implies a reduction in direct contact between canopies, an aspect to be considered relevant in canopy fire dynamics. For conifers, however, the release of a dominated layer must be evaluated for fire prevention purposes because this can become a determining factor in the creation of several continuous vertical layers capable of creating a critical scale of combustibles which, from lower layers can propagate the fire towards the crowns. It therefore becomes relevant to evaluate the spatial distribution and structure of the heights of the dominated layer.

Silvicultural intervention: articulate the vertical structure in the context of interventions in favour of candidate trees of sporadic species belonging to the dominated layer by applying a thinning intervention that reduces the density for small areas of intervention so as to create a spatial irregularity of the canopy.

Consistency/contrast with fire prevention: silvicultural interventions that operate by modifying the horizontal structure of the dominated layer, operating in favour of sporadic species, are to be considered favourable for fire prevention since they increase the horizontal structural heterogeneity of the plane itself with a non-uniform spatial criterion, based on the distribution of sporadic species. This may therefore make it possible to reduce the criticalities linked to the widespread and uniform mortality of the dominated plane with the consequent risk of the accumulation of deadwood on the ground over time. The favourable light conditions created around the tree of sporadic species, allowing a more harmonious development of the crown, are to be considered, in the long term, a determining factor in the development of a candidate capable of becoming a valuable seed-bearer in the perspective of a recolonisation dynamic post fire disturbance. Since in black pine formations specific enrichment in favour of broadleaves is always to be preferred, the creation of favourable light conditions in the dominated layer becomes fundamental for the more heliophilous species among them.

OB6. Encourage the presence of open areas and flowering herbaceous and shrub species.

Open areas in forests increase landscape diversity by influencing the composition and abundance of insect species (De Groot et al. 2016). Forest wildlife species facultatively utilise these gaps for food resources, due to the increased presence of blooms or for reproduction (Chiari et al. 2013; Emberger et al. 2016; Gittings et al. 2006; Hardersen et al. 2012). Large open areas are crucial for increasing biodiversity, while smaller areas

are preferable for species conservation (De Groot et al. 2016). The following interventions implemented may be consistent or contrary to fire prevention principles in IBs.

Silvicultural intervention: ensure the presence of open areas with a total area of between 200-400 m²/ha, possibly distributed in two units (this value includes open areas that may already be present).

Consistency/contrast with fire prevention: the presence of open areas without trees is to be considered a favourable aspect for fire prevention as it allows the dynamics of a fire to be modified. For openings of the dimensions proposed, this dynamic is limited to the reduction of heat in the layer occupied by the stand through the upward rise of hot air, which finds a preferential exit route upwards in the openings. If these dimensions are sufficient for the establishment of a lower layer of highly flammable shrubs, it is necessary to carefully evaluate the location of the artificially created openings regarding the morphology of the slope and the most probable trajectory of the fire in order to avoid conditions favourable to its propagation.

Silvicultural intervention: favouring the creation of open areas, reducing as far as possible the impact produced by their creation by operating in points of the site with predisposing characteristics e.g. the presence of edges already present, the presence of rocky areas bordering the area of intervention, opening small gaps that will subsequently be enlarged in the direction of favourable light.

Consistency/contrast with fire prevention: the widening of openings starting from favourable situations already present in the stand, such as stable margins produced by trees grown in stands with lower density, rocky areas, ridges or impluvium, is to be considered a favourable practice for fire prevention purposes because, operating from pre-existing structural or morphological conditions, it reduces the risk of generating a condition of mechanical instability in the stand, which may be followed by collapse or crashing of the trees with consequent accumulation of deadwood on the ground.

Silvicultural intervention: create openings in stands with dense, continuous cover by limiting the unit area to 100 m² and combining this cut with thinning in the stand adjacent to the edge to encourage diffuse light to enter the ground.

Consistency/contrast with fire prevention: for the purposes of fire prevention, the creation of these openings in pine stands is to be considered an irrelevant practice since the small surface area of the openings produced has no effect on fire dynamics. The thinning proposed on the remaining stand, to foster the entrance of diffuse light, goes in the direction of a structural articulation to be considered always favourable for the purposes of increasing the resistance and resilience of the stands. The effect induced will depend on the intensity of the thinning and how it is implemented. Particular attention must be paid to situations in which the light diffused to the ground is favourable to the development of a continuous herbaceous-arbustive layer capable of significantly modifying fire dynamics.

Silvicultural intervention: discourage the spread of any allochthonous species that may be present by avoiding creating openings near them so as not to encourage their proliferation by both agamic and gametic regeneration.

Coherence/contrast with fire prevention: for the purposes of the post-fire reconstitution dynamic, favourable to heliophilous pioneer species, the absence or scarcity of seed-bearing trees of allochthonous species is a determining element in the reconstitution of a stand characterised by the species typical of the vegetation strip to which it belongs.

Silvicultural intervention: avoid the creation of openings in very young broadleaf stands to prevent the uprooting of stumps with the production of shoots that will quickly, as they develop, cover the soil preventing the entry of herbaceous species.

Coherence/contrast with fire prevention: in black pine stands, the possible presence of young broadleaf individuals is to be considered as an opportunity to increase the specific richness and for this reason their management must have as its main objective that of breeding such individuals to produce seed, favouring early fructification. Coppicing, therefore, counteracting this objective is to be avoided unless the individuals present are in such a state of suffering that it does not guarantee adequate future development, even if favoured by silvicultural intervention. Coppicing may represent a management alternative to obtaining new vigorous individuals by agamic means, to be selected as candidates in future management.

OB7. Increase the amount of lying and standing dead wood.

It is estimated that between 20 and 40 per cent of forest trees, animals and fungi depend on dead or dying wood in at least one stage of their life cycle (Bauhus et al. 2019; Emberger et al. 2016). Maintaining different qualities of dead wood in terms of tree species, diameter, decay class and type (standing or ground) has a positive effect on the conservation of saproxylic species communities (Lachat et al. 2013). Furthermore, dead wood is not only recognised as a key element for saproxylic species but is also known for its important function in nutrient release and water retention (Lachat et al. 2013). Regarding the size of dead wood, larger sizes have been identified as essential for the conservation of saproxylic species for several reasons: being more heterogeneous, they provide more ecological niches and microhabitats, which in turn influence saproxylic species diversity (Lachat et al. 2013); size influences the stability of microclimatic conditions and the availability of the resource, as large deadwood decomposes more slowly, remaining available for a longer period, influencing larval development and the development of different stages of decomposition (Gossner et al. 2013; Motta 2020). Standing deadwood is important for bats and birds, which exploit these structural elements for feeding and nesting or roosting (Rigo et al. 2024); moreover, large elements are normally scarce in managed forests, and it becomes essential to preserve them (Gossner et al. 2013; Lachat et al. 2013). For the purposes of the project, the minimum diameter considered is 17.5 cm (Emberger et al. 2016) and the minimum target quantity is 20 m³/ha (Micò et al. 2022). The following interventions implemented may be consistent or contrary to the principles of fire prevention in IBs.

Silvicultural intervention: do not remove the wood produced by the cuts from the intervention areas.

Consistency/contrast with fire prevention: the total release of wood mass that accumulates on the ground following silvicultural intervention must be carefully evaluated both based on the fire risk of the individual IB and based on the volume released and its size. To this end, considerations must be based on the quantity, spatial distribution and quality of the deadwood produced by interventions with the objective of reaching the diametric equilibrium proposed by the H model to which reference is made for considerations on the subject.

Silvicultural intervention: to optimise a differentiation, both through cutting and girdling, of dead wood, declined according to more specific parameters.

Consistency/contrast with fire prevention (1- release density parameter): the diversification of the creation of dead wood in terms of space (set of close or isolated trees) is to be evaluated for fire risk purposes based on the diametrical development of the trees, i.e. the type of fuel that is released on the ground. In fact, the

production of deadwood elements of medium-high diameter does not represent a critical point for fire prevention purposes, so any accumulation of such elements does not represent a critical point. Greater attention should be paid to the management of brushwood in this respect.

Consistency/contrast with fire prevention (2- light exposure parameter): the release of fuel under different light conditions is to be considered a favourable factor for fire prevention, as different light conditions induce a different degree of moisture in the ground wood and thus a different degree of flammability, considering the same diameter

Consistency/contrast with fire prevention (3- moisture parameter): the release of fuel under different moisture conditions is to be considered a favourable factor for fire prevention, as the different conditions induce different degrees of flammability in the ground wood, considering the same diameter

Consistency/contrast with fire prevention (4- parameter spatiality): a spatially uniformly distributed release of the deadwood on the ground is, for the purposes of fire prevention, a critical issue as it creates a prerequisite for the continuity of the fuel and thus the potential flame front.

Consistency/contrast with fire prevention (5- parameter typology): for the purpose of the release typology, it becomes relevant to assess, for logs on the ground, the diameter of the accumulated elements, while for standing dead trees this aspect is not relevant.

Silvicultural intervention: applying the girdling technique, declined according to more specific objectives

Coherence/contrast with fire prevention (1- enhancing gradually light availability for a candidate tree causing the gradual death of the direct competitor avoiding sudden isolation with consequent stability problems): this practice can be critical for pine forests as the presence of a dead tree standing near a live tree can be a favourable element for the propagation of the crown fire.

Consistency/contrast with fire prevention (2- avoid damage to a candidate tree by felling the competing tree located nearby): this practice can be critical for pine forests because the presence of a dead tree standing near a live tree can be a favourable element for the spread of crown fire.

Consistency/contrast with fire prevention (3- favouring the decay of large senescent trees): the creation of standing dead trees through the technique of girdling can be a critical element if these trees, once dead, can become critical factors for the fire, favouring its propagation. A senescent or dead individual can propagate the fire from the lower levels of the stand to the crown, thanks also to elements linked to the reaction to the girdling such as resin flows.

Silvicultural intervention: encourage the differentiation of the type of dead wood by cutting the stumps at a height of 1 metre, so that they can also be anchoring elements of the dead wood produced and placed on the ground in sites with a risk of soil erosion

Consistency/contrast with fire prevention: this practice is to be considered indifferent to fire dynamics since the presence of high cut stumps is not a critical issue with respect to the spread or persistence of a fire in the stand.

Table 9 summarises the results of the analysis and any clarifications per OB and individual prescription.

Table 9 - Summary table of coherence between silviculture for biodiversity conservation on fire prevention aspects for Habitat 9530.

Prescriptions	Habitat 9530	Clarifications
OB1. Aim for a structure of maximum theoretical functionality		
eliminating, through cutting or girdling, the surplus trees compared to the reference H model for the habitat	potential conflict	depending on the intensity of removal and the release of logs to the ground
preserving or favoring those belonging to underrepresented diameter classes	potential conflict	if implemented at the expense of Large and Very Large trees
selecting individuals of a larger size class if the next class is underrepresented compared to the model	favorable	
favoring the creation of conditions conducive to the establishment of regeneration or the development of existing regeneration if the "saplings" class is poorly represented	potential conflict	depending on the possibility of creating a vertical continuity of fuel in the direction of the most probable fire spread
OB2. Promote the presence of very large trees (VLT) (diam. >57.5 cm)		
preserve existing VLT trees	favorable	
nominate a certain number of trees to promote their growth in younger stands through extensive selective thinning. In the "Poles" stage, the candidates to be favored are:		
i) with good mechanical stability (H/DBH<80)	favorable	
ii) with good crown depth (1/3 of the height)	potential conflict	depending on crown depth values deemed too high for crown fire dynamics
iii) with a well-developed and symmetrical crown	favorable	
nominate a certain number of trees to promote their growth in more advanced evolutionary stage stands through a tree-oriented silviculture approach. In the "Large category" stage, the candidates to be favored are:		
i) with a larger diameter within the stage (37.5-57.5 cm)	favorable	
ii) with actual direct competition	favorable	
when a group structuring is present, nominate a set of nearby trees by implementing an intervention that benefits the entire group (thus treating it as a single candidate)	potential conflict	depending on the risk of releasing groups with a vertical structure unfavorable to crown fire propagation (fuel ladder)
nominate underrepresented native species in the stand, provided they can develop into large-sized trees	favorable	
nominate underrepresented native species in the stand located in particular positions (e.g., near openings or specific edaphic conditions)	favorable	
OB3. Encourage the presence of habitat trees		
ensure greater longevity for trees with dendromicrohabitats through selective thinning in their favor to reduce direct competition from trees in the dominant or co-dominant layer, allowing more light to reach the crown level	favorable	
enrich the structural complexity of the stand near their presence by significantly reducing forest density in proximity to TrEM hosting birds or bats, making these trees more favorable for these faunal species	potential conflict	depending on the risk of fuel accumulation, potentially critical near the TrEM
include in the TrEM list the seed trees from previous coppice management, even if they lack dendromicrohabitats, and enhance their vitality and permanence through silvicultural interventions in their favor, as they are excellent potential TrEM trees	favorable	
OB4. Promote species diversity in the forest		
increase species richness by retaining all trees belonging to sporadic species	favorable	
promote the growth and development of trees belonging to sporadic species characterized by good vigor by reducing direct competition from other trees through selective thinning	favorable	
OB5. Promote a heterogeneous vertical structure		
structure the vertical composition of the stand by favoring candidate trees through thinning from above, removing direct crown competitors without intervening in the dominated layer	potential conflict	depending on the possible creation of continuous vertical layers capable of forming a critical fuel ladder concerning the most probable fire direction (for pine forests) or an undesirable accumulation of necromass due to sprout mortality (in chestnut groves)
structure the vertical composition by favoring candidates from sporadic species in the dominated layer by applying thinning that reduces density in small intervention areas, thus creating spatial irregularity in the canopy cover	favorable	
OB6. Encourage the presence of open areas and flowering herbaceous and shrub species		
ensure the presence of open areas covering a total surface between 200-400 m ² /ha, preferably distributed in two units (this value includes any pre-existing open areas)	favorable	
promote the creation of open areas while minimizing the impact of their creation by selecting site locations with predisposing characteristics (e.g., presence of existing edges, proximity to rocky areas) and creating small gaps that will later be expanded towards favorable light conditions	favorable	
create openings in stands with dense and continuous cover, limiting the individual surface area to 100 m ² and combining this cut with thinning in the adjacent stand margin to promote the penetration of diffuse light to the ground	potential conflict	depending on whether the penetration of diffuse light is sufficient to form a continuous herbaceous-shrub layer unfavorable for fire propagation dynamics
discourage the spread of any present non-native species by avoiding the creation of openings near them to prevent their proliferation both vegetatively and sexually	favorable	
avoid creating openings in very young broadleaf stands to prevent sprout regrowth, which would quickly develop and cover the ground, inhibiting the establishment of herbaceous species	favorable	
OB7. Increase the amount of deadwood on the ground and standing		
do not remove the wood produced by cuts from intervention areas	potential conflict	depending on the quantity, distribution, and quality of the necromass produced by the intervention
optimize differentiation, both through cutting and girdling, of deadwood in terms of:		
i) material density (accumulation of trees and individual trees)	potential conflict	depending on the diameter growth of the trees, which determines the type of fuel released to the ground
ii) illumination (in light and in shade)	favorable	
iii) humidity (in valleys or depressions)	favorable	
iv) spatiality (favoring concentration over regular distribution)	favorable	
v) type (standing or on the ground)	favorable	
apply the girdling technique to:		
i) gradually expose the crown of a candidate tree by causing the gradual death of its direct competitor, avoiding sudden isolation that could cause stability issues	potential conflict	depending on the creation of a favorable condition for crown fire propagation due to the presence of a dead tree standing near a living one
ii) avoid damaging a candidate tree when felling a nearby competing tree	potential conflict	depending on the creation of a favorable condition for crown fire propagation due to the presence of a dead tree standing near a living one
iii) promote the decline of large-sized senescent trees	potential conflict	depending on the possibility of creating conditions favorable to resin flow formation or dead trees near living ones
promote the differentiation of deadwood types by cutting stumps at a height of 1 meter so they can also serve as anchor points for deadwood placed on the ground in areas at risk of soil erosion	indifferent	

2.4. Self-resistance in Habitat 9530 stands: prescriptions in the areas of intervention outside the CA and IB, perimeter to the IB and on Habitat Trees (HT)

This section describes the preventive silvicultural criteria to be implemented in fire-disturbance infrastructure in black pine stands - Habitat 9530 outside the CA and IB or possibly in their perimeter strips. Silvicultural prescriptions for Habitat Trees (HT) are also illustrated. The summary of the parameters proposed in the chapter is illustrated in **Figure 54**, **Figure 55** and in the mind map shown in **Figure 56**.

For CA, preventive silviculture interventions must always be implemented for self-resistance in stands located outside of them and in the direction of the most probable fire. The depth of the intervention strip must be greater than 100 meters and its width must vary according to the steepness and morphology of the slope.

For the IBs, preventive silviculture interventions for self-resistance are always to be implemented when, in the analysed area, they are those with the highest fire hazard and the greatest size. For IBs that fall in this situation and are classified as "conservative", interventions must be carried out only on the forest stand outside these and in the direction of the most probable fire. The depth of the intervention strip must be greater than 50 meters and its width must vary according to the steepness and morphology of the slope. For IBs classified as "improved", interventions in stands outside these are always to be envisaged (always for a strip > 50 m) and, if deemed functional to the effectiveness of external interventions, internal interventions are also to be envisaged, always in the direction of the most probable fire, for a strip 30-50 m deep.

For Habitat Trees located in the portions of the district with the highest fire hazard, it is always necessary to implement preventive silviculture interventions for self-resistance by operating, in the lower canopy layer (combustible management), for a band of at least 5-10 meters radius from the trunk, and in the upper canopy layer for a band of at least 5 m from the outer perimeter of the latter.

The prescriptions are distinguished by distinguishing between activities that are charged to stands and activities that are charged to surface fuels.

Stand requirements

- ✓ Design a grid of elliptical openings of variable size (250-1100 m²) on two levels. A first level with larger gaps with the major axis (3-4 times the average height of the stand) oriented along the expected direction of propagation of the crown fire, and a second level with smaller gaps (1-2 times the average height of the stand) branching off transversally from the main gaps.
- ✓ obtain at least 30% of openings in the intervention area. The gaps must ensure a minimum distance of 10 m between the crowns of the trees on the opposite edges along the minor axis.
- ✓ depending on the initial structure, carry out variable tree harvesting in terms of volume/ha, basal area/ha and trees/ha, trying to favour a group structure, even in stands that tend to be even-aged such as black pine forests.
- ✓ fragment the extended, single-layer groups in such a way as to articulate the structure into small groups (2-4 trees, approx. 40/ha), medium groups (5-9 trees, approx. 10/ha) and isolated trees with fire-resistant and stable characteristics (50/ha).
- ✓ take care of the release of stable trees and groups, to prevent the effects of wind and heavy snow crashes and to favour less flammable species (broad-leaved trees).
- ✓ manage the regeneration: do not directly favour its establishment in critical points, orienting the gaps so that there is plenty of direct light in the morning hours; conversely, favour it in the remaining portions of the stand by ensuring a certain amount of morning shade.

Management of surface fuels

- ✓ reduce surface fuels at critical points: impluvium areas, slope changes.
- ✓ maintain a maximum of 20 per cent of the flammable shrub cover with a maximum height of 2 m, taking care not to leave any fuel on the ground.
- ✓ reduce fine surface fuels (litter, grasses and deadwood with diameters < 2.5 cm) to bring the load below 15 t/ha.
- ✓ Manual surface fuel reduction interventions: scrub clearance and reduction of deadwood with a chainsaw and brush cutter. Cut and spread the unremoved deadwood adhered to the ground as much as possible, avoiding accumulations, especially at the base of stems and at or downstream from groups of trees.
- ✓ where possible, burn cutting residues in piles with a volume < 3 m steres.
- ✓ mechanical surface fuel reduction operations: carry out chopping on slopes < 15% and on sites with good accessibility and no rocky outcrops.
- ✓ prescribed burn: reduce litter load by at least 70% and deadwood load by 50% with $D \leq 2.5\text{cm}$. Limit the mortality of the tree stands with $D \geq 15\text{cm}$ to within 5%. To this end, operate with a flame intensity < 200 kW/m and work in the presence of wind that disperses the heat and draws it away from the crowns. Use the linear upwind and slope ignition technique or the spot ignition technique if it is ignited no more than 2m from the design fire front, to operate with more conservative values of flame length and propagation velocity - compatible with a prescribed burn site under coniferous canopy.

3. Fire prevention planning and habitat conservation at the landscape

3.1. Common methodology

Task 3.2 of the GoProForMed project developed a **replicable methodology** to assess the trade-offs between fire prevention planning dedicated to the protection of Natura 2000 habitats and planning for fire risk mitigation in urban-rural interface areas and in areas where forest stands perform general soil protection and biomass and carbon stock production functions. The methodology developed uses the models and functions of the FlamMap decision support system, which is widely used for fire prevention planning (Finney 2004). This model made it possible to test **alternative scenarios of priorities** to protect with preventive infrastructure planning in the Natura 2000 sites of Pratomagno (Italy) and Prades (Spain). In both sites, the starting point was the respective fire prevention plans at the territorial scale and the current strategic planning of preventive infrastructures involving 1% of the treated territory. The scenarios tested are: i) **Absence of prevention - PRE**: scenario in which no preventive infrastructure is planned; ii) **Business as usual - BAU**: current planning approach found in the two territories analysed that does not prioritise biodiversity conservation; iii) **BIO**: priority given only to CA and IB as defined by GoProForMed; iv) **TRADE-OFF**: compromise between the two alternative scenarios, **keeping 1%** of the total treatable area **constant**. The methodology developed and its application to GoProFoMed sites are described below.

3.1.1. Definition of fire risk

Fire risk emerges from the combination of **fire hazard** in a given area that could occur over the years and the **potential impact** of these fires. In Deliverable 3.2 the spatial distribution of fire risk at the landscape scale derives from the integration of the different risk components such as: i) **probability of ignition** and spread of the flame front, ii) **expected fire behavior** expressed as linear intensity of the flame front, iii) **vulnerability** of interface areas and ecosystem services: general soil protection, biomass and carbon stock, Natura 2000 habitats, CA and IB as defined by the GoProForMed project, iii) **exposure** of urban-rural interface areas and key ecosystem services. In the following paragraphs, the individual components of fire risk are analysed and how each level of information is implemented for each case study.

3.1.1.1. Fire hazard

Fire hazard (hazard) is understood as the **probability** of a fire of a certain **intensity** occurring. In order to define the hazard at a landscape scale, the probability of fire occurrence is used, and the expected fire behaviour is estimated with reference to the linear intensity (expressed in kW/m) potentially attainable by the flame front. The objective of the probability analysis is above all to test the fire's spread potential, while the mapping of the potential intensity provides information that can be compared with the fire-fighting capacity of the fire-fighting system and the potential impact on the ecosystem. The methodology identified for the construction of the information layers and their combination to produce the final thematic map is described below.

The evaluation of fire behaviour is carried out through the implementation of appropriate numerical fire simulation models starting from the input data relating to the variables involved in fire propagation. The **FlamMap application** (Finney 2004), an **open-source** application developed by the Forest Service of the USDA (United States Department of Agriculture), was used to simulate fire behaviour and to produce the map of fire probability and potential fire intensity. This model allows to simulate, map and analyse the characteristics of forest fire potential behaviour in a two-dimensional environment by exploiting the semi-empirical model developed by Rothermel (1972). Furthermore, it allows the effect of strategic prevention planning to be evaluated in terms of variation in potential fire behaviour. By simulating alternative scenarios of prevention planning (quantity of fire prevention interventions on the territory and their spatial distribution) it makes it

possible to compare which solutions are more effective in mitigating fire severity (Finney 2006) in exposed areas, i.e. Natura 2000 habitats, CA and IB, urban-rural interface areas, etc.

The first step is to generate the simulation environment - **landscape file** - containing all the morphological and vegetational characteristics of the environment within which the fire behaviour is to be analysed. Five inputs (ASCII format files) containing topography and fuel characteristics are required for this step. The dimensions of the landscape were defined considering the extension of the Pratomagno and Prades Natura 2000 areas being planned for the purposes of the GoProForMed project and the potential for the development of large fires in the area, to take into account events that are triggered even far from the SCI but have the potential to spread as far as the SCI.

The different inputs (raster files, resolution: 20x20 m) used in the FlamMap model are:

- Elevation - altitude (m a.s.l.);
- Slope - slope (°);
- Aspect - exposure (°N);
- Fuel model - fuel models attributed to each land use (Scott & Burgan, 2005);
- Canopy cover (%), using the Tree Cover Density map calculated for 2018 by the Copernicus project.

The second step consists of defining the simulation inputs: i) the **meteorological scenario**, which includes the parameters of live and dead fuel moisture (fuel moisture file), the foliar moisture content and the crown fire calculation method; ii) the **wind scenario**, i.e. the parameters of wind speed (in km/h) and prevailing direction (in ° relative to N) of the wind.

Once the environmental conditions on which to base prevention planning are defined, the type of simulation is chosen according to the desired outputs. The analyses performed are: i) **Burn Probability** analysis; ii) **Potential Fireline Intensity** analysis; iii) **Preferential Trajectory** analysis.

The **fire-travel probability** analysis for the study area was carried out by simulating **5000 fires lasting 48 hours** (2880 minutes) using the Minimum Travel Time (MTT) function with a calculation resolution of 40 m. The 5000 ignitions were distributed over the fire territory (forest and grassland) proportionally according to two methods: i) random method = 10% of the ignition points (500 pt.); ii) schematic method = 30% of the ignition points (1500 pt.); iii) probabilistic method = 50% of the ignition points (3000 pt.).

The **random method** represents the component of fires linked to natural causes (mainly lightning strikes), which are the smallest proportion of fire causes in Europe. The **schematic method** represents stochastic fires linked to natural and anthropogenic causes (i.e. sparks from high voltage linear infrastructure cables). It was decided to distribute the points: according to a regular grid, to avoid underestimating the probability of ignition of certain portions of the territory. The **probabilistic method** represents the component of fire probability as a function of anthropic activities (main causes of ignition) and, therefore, the distribution of the points with this method was carried out as a function of proximity to anthropic pressure zones using the road network as a proxy. The fire probability was calculated proportionally to the number of times a pixel was traversed by the 5000 simulated fires.

The **potential linear intensity** was simulated using FlamMap's 'Fire behaviour' module, which determines for each pixel in the landscape the linear intensity in kW/m indicative of the potential behaviour that can develop at that point depending on fuel flammability, wind and slope gradient.

All the simulations envisaged a **synoptic wind scenario** characterised by winds with a standard average speed of 15 km/h and a prevailing wind direction representative of the conditions predisposing the fire phenomenon in each case study as deduced from the respective spatial plans: i) Pratomagno: SE (135°); ii) Prades: NW (315°). In addition, all simulations adopted the **D1L1 moisture scenario** (Scott & Burgan, 2005, **Table 10**), which involves the dehydration of both live and dead fuel components. For canopy fuels, no

specific landscape file input themes were calculated, canopy moisture was set at 100% and Finney (2004) was used as the propagation method.

Table 10 - Moisture values of dead (divided into fuel classes according to Pyne et al. 1996) and live (Scott & Burgan, 2005) fuels.

Scenario	D1 - Low			L1 - Fully cured, Very low	
Status	Dead fuel			Live fuel	
Component	1h	10h	100h	Grass	Shrub
Humidity (%)	3	4	5	30	60

Once the fire probability and potential intensity were calculated, they were divided into 6 classes (Null, Very Low, Low, Medium, High, Very High) using certain thresholds derived from the simulations performed as shown in **Table 11**.

Table 11 - Thresholds of the 6 Fireline Intensity and Burn Probability classes of the two case studies.

	Italy - Pratomagno		Catalunya - Prades	
Class	Fireline Intensity (kW/m)	Burn Probability	Fireline Intensity (kW/m)	Burn Probability
Null	0	0	0	0
Very Low	0-100	0-0.001	0-100	0-0.3
Low	100-250	0.001-0.009	100-250	0.3-0.5
Medium	250-500	0.009-0.015	250-500	0.5-0.8
High	500-1000	0.015-0.025	500-1000	0.8-0.91
Very High	>1000	>0.025	>1000	>0.91

In order to define the fire hazard, a combination matrix between the classes of probability of occurrence and those of potential linear intensity was then developed to divide the hazard into 6 classes (Null, Very Low, Low, Medium, High) as shown in **Table 12**.

Table 12 - Hazard class combination matrix, as a combination of probability and intensity classes.

	Fire probability						
Potential intensity	Hazard	Very High	High	Medium	Low	Very Low	Null
	Very High	Very High	Very High	High	High	Medium	Null
	High	Very High	High	High	Medium	Low	Null
	Medium	High	High	Medium	Low	Low	Null
	Low	High	Medium	Low	Low	Very Low	Null
	Very Low	Medium	Medium	Low	Very Low	Very Low	Null

	Null	Null	Null	Null	Null	Null	Null
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3.1.2. Potential impact

The potential impact of forest fires emerges from the **vulnerability** of urban-rural interface areas and areas that provide key ecosystem services and their **exposure** to fire disturbance. The potential impact is also calculated using a combination matrix, expressed through 5 classes (Very Low, Low, Medium, High, Very High).

Vulnerability represents the susceptibility of the ecosystem and its functions to disturbance by fire and is defined as the capacity for resistance and resilience following the passage of fire. Vulnerability is calculated using a combination matrix of the following ecosystem services:

- **Biodiversity:** fire sensitivity of Natura 2000 habitats and presence of Core Areas (CA) and Islands of Biodiversity (IB) of target Mediterranean habitats to be protected.
- **Biomass and carbon stock:** amount of epigeal biomass present.
- **Soil protection:** protection function against soil erosion.
- **Civil protection:** protection function of urban-rural interface areas.

Biodiversity: the fire sensitivity of the Natura 2000 Network (RN2000) habitats present within the study site is defined as a set of resistance and resilience traits. Resilience is related to the physical/mechanical characteristics of individual species in protecting themselves from fire and maintaining vitality. Resilience to the passage of the flame front measures the ecosystem's ability to re-establish conditions prior to disturbance. Depending on its resistance and resilience characteristics, a habitat is defined as **sensitive**, **indifferent** or **tolerant** to the passage of fire. A habitat is considered sensitive if the dominant species that compose it have not developed adaptations to fire and therefore their survival and capacity to recover after disturbance are compromised by the passage of fire. Conversely, a habitat is considered tolerant when the dominant species benefit from the passage of fire, which allows them to renew themselves and/or remain more competitive compared to other species. Finally, habitats that derive neither benefit nor disadvantage from the occurrence of fire are considered indifferent to fire. Based on the scientific literature (**Annex A**), each habitat present in the study area was assigned one of the 3 fire sensitivity classes (Low, Medium, High), while non-flammable surfaces (water, urban, bare soil) were assigned to the null class (Null). The project target habitats (habitats 9260 and 9530*) were assigned to the sensitivity class High (i.e. class 3).

The Core Areas (CA) and Islands of Biodiversity (IB) of the target Mediterranean habitats (habitats 9260 and 9530*) are the biodiversity conservation objectives to be protected identified within the site by Task 3.1. They are therefore considered priority objectives in fire planning at the landscape scale; therefore, the portions of territory that fall within these areas are directly assigned the High fire sensitivity class 3.

Biomass and carbon stock: the vulnerability of this ecosystem service by the forested areas in the two case studies is represented by the amount of total forest biomass present (ton/ha) at a resolution of 100 m obtained from the Copernicus programme¹. Five classes of total forest biomass were identified (Very Low, Low, Medium, High, Very High) with which the area of interest was classified (**Table 13**).

¹ <http://data.europa.eu/89h/6d2cb333-7a81-4249-af30-18b2a91a8a90>

Table 13 - Thresholds of the 5 biomass and carbon-stock service classes of the two case studies.

	Italy-Pratomagno	Catalunya-Prades
Class	Forest Biomass (ton/ha)	Forest Biomass (ton/ha)
Very Low	0-1	0-1
Low	1-109	1-32
Medium	109-170	32-63
High	170-231	63-95
Very High	>231	>95

Soil protection: the soil erosion protection function is quantified by calculating the Revised Universal Soil Loss Equation (RUSLE) proposed by Renard et al. (1997):

$$A = R \times K \times L \times S \times C$$

where:

A: soil removed by water erosion (t·ha⁻¹·year⁻¹);

R: erosivity of precipitation (MJ·mm·h⁻¹·ha⁻¹·year⁻¹);

K: soil erodibility, which is the soil loss per unit of R (t·h·MJ⁻¹·mm⁻¹);

L: length of the slope (dimensionless);

S: slope gradient (dimensionless);

C: land cover factor (dimensionless);

For both case studies, the map generated through the RUSLE 2015 model (a modified version of the RUSLE model) by Panagos et al. (2015) was used, which estimates soil loss in tons/ha/year at a resolution of 100 m based on the best available data². Based on the erosion rate (ton/ha/year), the land was divided into 5 classes (Very Low, Low, Medium, High, Very High) as in **Table 14**

Table 14 - Thresholds of the five soil erosion protection classes of the two case studies.

	Italy-Pratomagno	Catalunya-Prades
Class	Soil erosion (ton/ha/year)	Soil erosion (ton/ha/year)
Very Low	0-1	0-1
Low	1-50	1-45
Medium	50-100	45-90
High	100-150	90-135
Very High	>150	>135

² <https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015>

Civil protection: the civil protection function relates to the urban-rural interface zones, i.e. those areas where human activities encounter flammable vegetation and influence the fire phenomenon by modifying the frequency and number of ignitions. The interface zone is materialised by a 100 m buffer built around urbanised areas and the road system (50 m downstream and 50 m upstream of the ordinary road system). The civil protection function is a priority objective of fire planning; therefore, the portions of territory that fall within the interface buffer are directly assigned the Very High fire sensitivity class.

Exposure represents the functional value attributed to the natural resource and the relative degree of conflict with the passage of fire. The most important elements of vulnerability are:

- Presence of CA and IB of the target Mediterranean habitats (habitats 9260 and 9530*) (Biodiversity).
- Presence of flammable habitats (Habitat).
- Presence of forest ecosystems with significant amounts of biomass (Forest Ecosystem Services).
- Presence of significant soil erosion (slopes > 40 %) (Soil erosion).
- Urban-rural interface zones (Urban-wilderness interface).

A raster (100 m x 100 m) has been generated for each exposed service where: 1 represents the presence of the exposed service or, in the case of soil erosion, the occurrence of predisposing conditions and, therefore, a possible conflict with the occurrence of fire; 0 represents the absence of vulnerability/ predisposing conditions, resulting in a lack of conflict with the possible passage of fire. Exposure is calculated as a 0-1 raster combination matrix and is expressed in 5 classes.

Finally, the **potential impact from fire** was calculated through a combination matrix of vulnerability and exposure classes in order to divide the overall vulnerability into 5 classes (Very Low, Low, Medium, High, Very High) (Table 15).

Table 15 - Combination matrix of potential impact, as a combination of vulnerability and exposure classes.

Vulnerability	Exposure					
	Potential impact	Very High	High	Medium	Low	Very Low
Very High		Very High	Very High	High	High	Medium
High		Very High	High	High	Medium	Low
Medium		High	High	Medium	Low	Low
Low		High	Medium	Low	Low	Very Low
Very Low		Medium	Medium	Low	Very Low	Very Low

3.1.3. Fire risk

The fire risk results from the multiplication of the potential impact with the hazard:

$$\text{Fire risk} = \text{potential impact} \times \text{hazard}$$

The spatialisation of risk is obtained by means of a combination matrix of hazard and potential impact, expressed through 6 risk classes (Null, Very Low, Low, Medium, High, Very High), as in **Table 16**.

Table 16 - Combination matrix of hazard classes, as a combination of potential impact and hazard classes.

		Dangerousness					
Potential impact	Risk	Very High	High	Medium	Low	Very Low	Null
	Very High	Very High	Very High	High	High	Medium	Null
	High	Very High	High	High	Medium	Low	Null
	Medium	High	High	Medium	Low	Low	Null
	Low	High	Medium	Low	Low	Very Low	Null
	Very Low	Medium	Medium	Low	Very Low	Very Low	Null

3.1.4. Pre- and post-scenario fire prevention hazard analysis

For each case study, using the simulation parameters described in **Section 3.1.1**, the potential fire **hazard in the absence of preventive infrastructure** was simulated. The method involved calculating: i) **probability of travel in the absence of prevention (BP PRE)**; ii) **potential linear intensity in the absence of prevention (FI PRE)**. In addition, the **fire size list (fsl PRE; .csv)** was extracted for both case studies, showing the burnt area (ha) of all 5000 simulated potential fires from each ignition point. The **hazard in the absence of prevention (Hazard PRE)** was then calculated.

To simulate the **BAU (Business as Usual) scenario**, a new simulation was carried out using the same ignition points and the same humidity and wind parameters. However, in this scenario, the **preventive infrastructures envisaged** and described in the territorial scale prevention plans in force at the two sites of Pratomagno and Prades were spatially inserted and parameterised, which envisaged the implementation of interventions for **1% of the ignitable surface (BAU Treatments)**. In the BAU scenario the priority objective of

fire prevention is civil protection. The following were obtained as outputs: i) the fire probability of the business as usual scenario (**BP BAU**); ii) the fire size list of the business as usual scenario (**fsl BAU**; **.csv**).

3.1.5. Strategic planning of preventive infrastructures using the Treatment Optimisation Model and calculation of post-treatment optimisation BP

The **1% of the flammable area** provided for in the current planning was reallocated using the Treatment Optimisation Model (TOM) function of the FlamMap application. This model requires three input files:

- ignition points responsible for the largest potential wildfires (max ignition points);
- landscape file of current conditions in the absence of management (landscape PRE);
- landscape file of ideal conditions, showing the maximum treated surface area under the assumption of unlimited resources for fire prevention interventions (landscape ideal).

The first step consisted in associating each simulated potential fire, contained in the *fire size list* extracted from the pre-intervention simulation (fsl PRE), with the ignition point that generated it. Then, by superimposing a regular hexagonal grid over the study area, the ignition points (max ignition points) responsible for the potential wildfires with an area >100 ha within each 2000 ha hexagon were selected.

The second step consisted in identifying potential areas in which fire prevention interventions could be implemented (**Treatment Opportunities**) in addition to the treatment areas provided for by the current prevention instruments (**Treatments BAU**). The Treatment Opportunities were identified by the following criteria:

- accessibility, i.e. reachable areas within a buffer of 100 m from the road network;
- slope of less than 30%, i.e. areas where mechanisation is possible;
- public ownership, i.e. larger areas on average and attributable to a single owner.

Next, the **ideal landscape** was generated by modifying the **PRE landscape**, assuming the implementation of fire prevention measures on 100% of the areas identified by the Treatment Opportunities and Treatments BAU.

Therefore, the TOM was run using the inputs described above to obtain the most **efficient and effective (i.e. optimised)** distribution of the surface area to be treated for civil protection purposes (TOM BAU). The choice was made to space the interventions over **1% of the total inflammable surface** of the study area, which is equal to the minimum treated surface area envisaged by the territorial plans in force in the two case studies and representative of the number of resources available for fire prevention.

Using the simulation parameters described in section 3.1.1, the following was simulated: i) the probability of travel (**BP BAU optimised**) if the fire prevention measures as spatialised by the TOM BAU had been implemented; ii) the fire size list was extracted (**fsl BAU optimised**; **.csv**).

3.1.6. Strategic planning of preventive infrastructure to protect biodiversity using TOM and post-intervention BP calculation

For the spatialisation of interventions with the aim of **protecting the project's target habitats**, using the simulation parameters described in **section 3.1.1**, preferential trajectories (*Major Paths*) were simulated from the max ignition points using FlamMap's *Minimum Travel Time* (MTT) function. Then, the ignitions responsible for the trajectories intersecting the Core Areas and Islands of Biodiversity (**max ignition points BIO**) were selected. Then, the TOM was run using the max ignition points BIO and the landscape ideal (**section**

3.1.3) to obtain the most efficient distribution of the area to be treated for biodiversity protection purposes (**TOM BIO**). The choice was made to space the interventions over 1% of the total surface area of the study area, equal to the minimum treated surface area envisaged by the plans in force in the two case studies.

Using the standard simulation parameters (**Section 3.1.1**), the following was simulated: i) probability of travel (**BP BIO**) assuming the implementation of the biodiversity protection measures as spatialised by the TOM BIO; ii) extracted fire size list (**fsl BIO; .csv**).

3.1.7. Strategic planning of preventive infrastructure to achieve the TOM trade-off and calculation of post-intervention BP

To achieve the best and most efficient compromise in the spatialisation of the area to be treated to simultaneously achieve hazard reduction for civil protection and biodiversity conservation purposes, i.e. **the TRADE-OFF scenario**, the *Treatment Optimisation Model* function of the FlamMap application was used as inputs:

- max ignition points as ignition points;
- landscape ideal generated by modifying the PRE landscape assuming the implementation of fire prevention interventions on 100% of the intervention areas identified by the TOM BAU and TOM BIO.

It was decided to space the interventions over 1% of the total area of the study area, which is equal to the minimum treated area required by the current plans in the two case studies.

Using the simulation parameters described in **section 3.1.1**, the probability of travel (**BP TRADE-OFF**) was simulated assuming the implementation of both fire prevention and biodiversity protection interventions as spatialised by the TOM and the Fire size list was extracted (**fsl TRADE-OFF; .csv**).

3.1.8. Evaluation of the variation in fire probability and distribution of potential fires

An assessment of the probability of travel was performed by calculating the Burn Probability index (**BP index**) as the ratio of the **average probability of travel** in a given preventive infrastructure planning scenario (mean BP scenario) to the average probability of travel in the no-management scenario (mean BP PRE):

$$BP\ index = \frac{mean\ BP\ scenario}{mean\ BP\ PRE}$$

The BP index was calculated for each of the preventive infrastructure planning scenarios:

- Business As Usual (BAU);
- Business As Usual optimised (BAU optimised);
- Biodiversity (BIO);
- Trade-Off (TRADE-OFF).

The BP index was calculated:

- for the areas of the landscape that fall into the **Very High fire risk class (paragraph 3.1.3)** in a no fire prevention scenario, i.e. the risk identified through the combination of the **potential impact map (paragraph 3.1.2)** with the **Hazard PRE map (paragraph 3.1.1)**;

- for **each ecosystem service exposure layer** (Biodiversity; Biomass and carbon stock; Soil protection; Urban-rural interface).

Finally, the **distribution in size classes** of the potential fires generated in the different treatment spatialisation scenarios was assessed and their relative frequency in the different size classes.

The comparison between the values of the indices described (BP index, fire size list) makes it possible to **evaluate alternative scenarios of strategic planning of preventive infrastructures**. This analytical comparison represents a tool to support decisions on possible trade-offs between different priority objectives (biodiversity, civil protection, ecosystem functionality) to be protected in fire risk mitigation strategies in a territory.

3.2. Analysis for the Pratomagno site

3.2.1. Location and description of the site

The study area is located in Tuscany, central Italy (**Figure 10**), mainly in the province of Arezzo (72%), has an extension of 105566 ha and its surface area covers 27 municipalities (**Table 17**). The Natura 2000 Network Site "mountain pastures and bushes of Pratomagno" (IT51180011) (hereinafter referred to as "Pratomagno") is located entirely in the province of Arezzo, has an extension of 23244 ha and covers 8 Tuscan municipalities (**Table 18**).

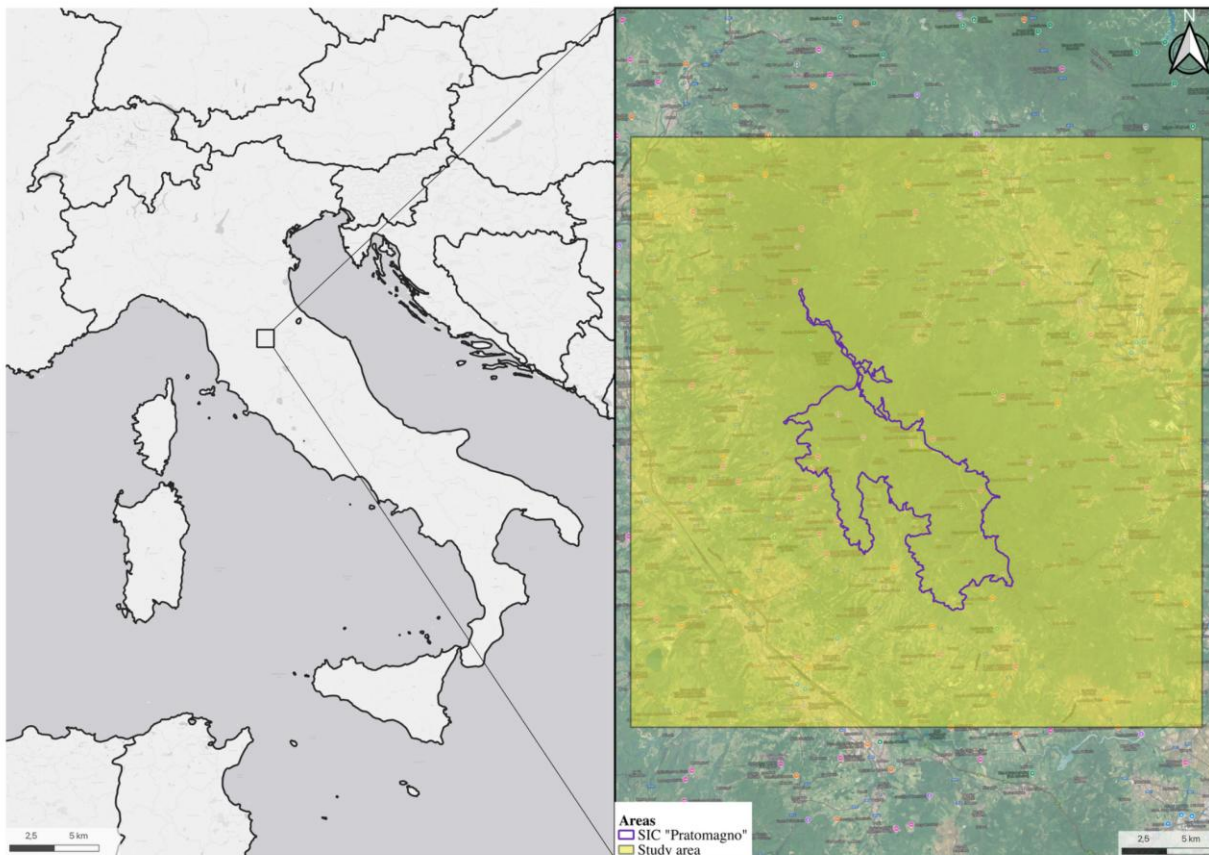


Figure 10 - Location of the study area.

Table 17 - Surface area of the 27 Tuscan municipalities covered by the study area.

Municipalities	Area (ha)	Municipalities	Area (ha)	Municipalities	Area (ha)
Reggello	12108	Castel Focognano	5594	San Giovanni Valdarno	2144
Loro Ciuffenna	8649	Pelago	5293	Rufina	2103
Terranuova Bracciolini	8423	Bibbiena	4984	Montevarchi	1426
Castel San Niccolò	8324	Ortignano Raggiolo	3629	Arezzo	846
Poppi	8036	Capolona	3394	Laterina Pergine Valdarno	831
Talla	5986	Cavriglia	3307	Chiusi della Verna	531
Pratovecchio Stia	5813	Figline and Incisa Valdarno	2638	Rignano sull'Arno	395
Castelfranco Piandiscò	5598	Montemignaio	2594	Pontassieve	246
Municipalities	Area (ha)	Castiglion Fibocchi	2545	Londa	66

Table 18 - Surface area of the 8 Tuscan municipalities involved in the "Pratomagno" Natura 2000 Network Site.

Municipalities	Area (ha)
Loro Ciuffenna	4283
Castelfranco Piandiscò	1763
Castel San Niccolò	358
Castel Focognano	161
Talla	130
Montemignaio	34
Reggello	15
Ortignano Raggiolo	8

The study area is characterised by an average altitude of 543 m a.s.l., an average slope of 16%, and a predominantly 181° exposure (**Figure 11**). Furthermore, on average, there is a high and continuous tree cover, especially in the area of the Pratomagno SCI (**Figure 12**).

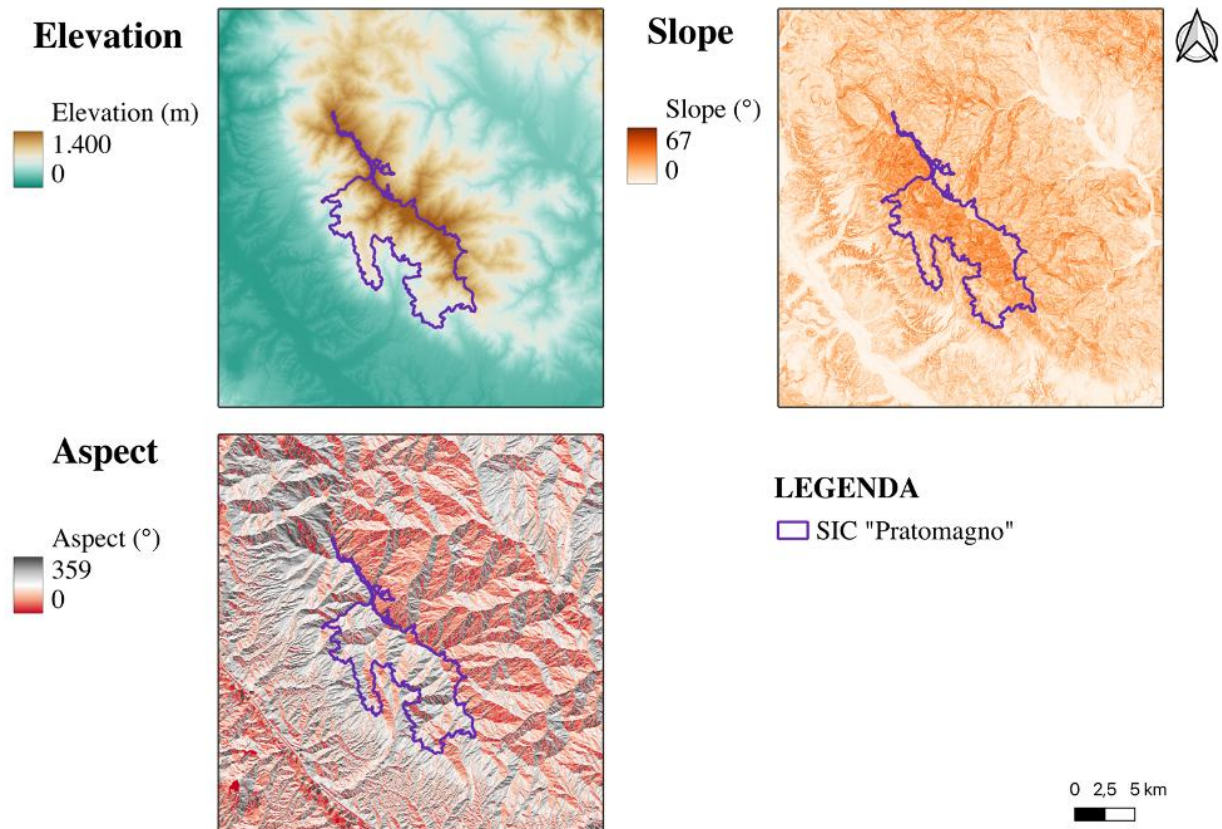


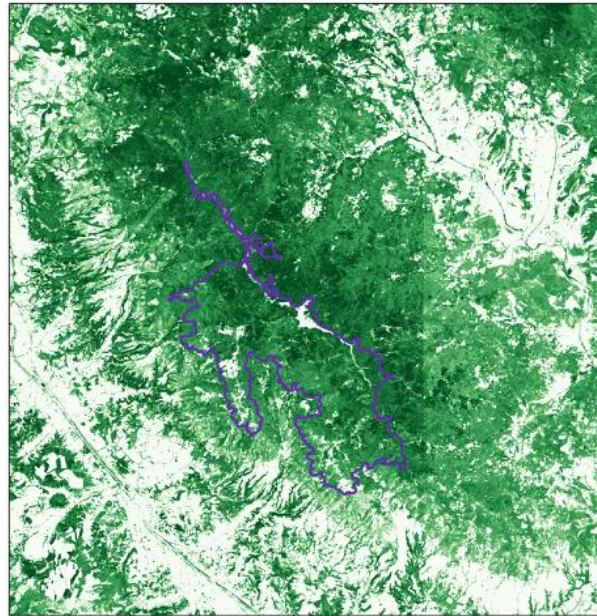
Figure 11 - Cartographies of the morphological elements of the study area.

Canopy cover

Canopy cover (%)
100
1

LEGENDA

□ SIC "Pratomagno"



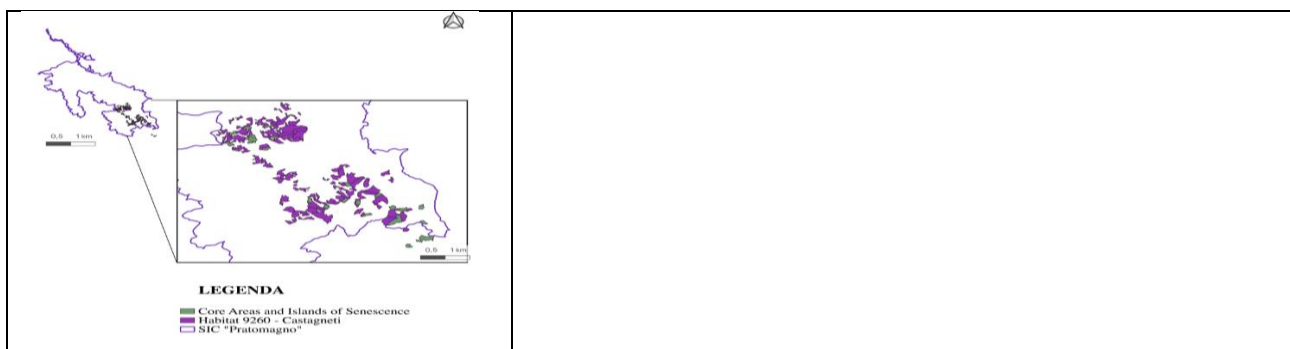
0 2,5 5 km

Figure 12 - Tree cover in the study area.

3.2.2. Biodiversity (sensitivity/adaptation, number/size/description of habitats)

In the study area there are 82 habitats, listed in **Annex A**. In particular, in the Pratomagno site, the Mediterranean habitat of the Natura 2000 Network project target "9260 - Chestnut forests" is present; within these areas the Core Areas (CA) and the Biodiversity Islands (IB), biodiversity conservation objectives, have been identified by Task 3.1 (**Figure 13**).

Habitat 9260 covers a surface area equal to 1% of the SCI (226 ha), while the biodiversity conservation objectives (CA and IoS) amount to 0.14% (32 ha) of the Pratomagno SCI surface area. The most widespread habitat within the study area is deciduous oak woodland, which covers an area of 19466 ha (18.5% of the study area) (**Figure 14**), while the most widespread habitat within the SCI is chestnut woodland (26.4% of the SCI), followed by beech woodland (16% of the SCI) and deciduous oak woodland (11.7% of the SCI).





To complete the thematisation of the FlamMap Device Support System simulation environment and to arrive at the definition of the fuel model map, land uses were investigated. Due to the lack of a single, comprehensive vegetation map for the entire area under analysis, numerous information layers were mosaicked, starting with the most detailed layers and filling in the gaps with maps of decreasing detail. The starting point was the land-use map of the Pratomagno Site, after which a merge was made between this

map and the land-use map drawn up on the drafting of the Pratomagno Specific Prevention Plan; finally, the gaps in the landscape area were filled in using the Corine Land Cover 2018 IV Level map.³

To produce the map, a fuel model of Scott and Burgan's (2005) 40 was associated with each land use; in particular, agricultural areas were assigned a fuel model that considers the most unfavourable situation for fire propagation (model 181) (**Figure 15**).

The fuel models with the largest presence in the study area are model 184 and model 93. The area occupied by these models represents 57.3 % of the surface area of the study area.

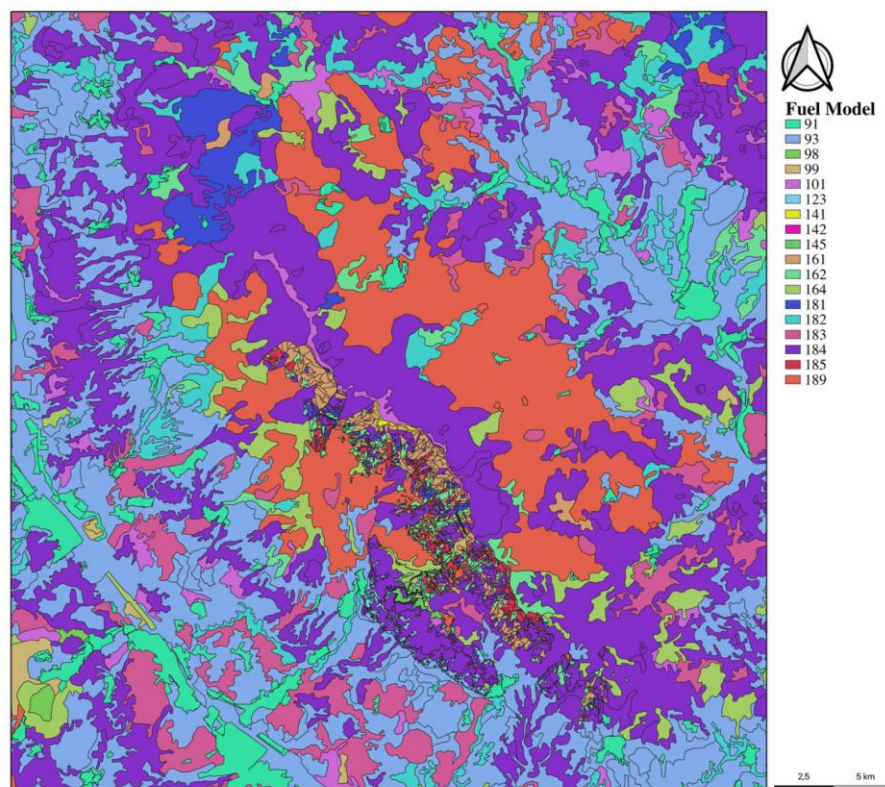


Figure 15 - Fuel model map, FlamMap input.

3.2.4. Types of interventions

At present, silvicultural interventions are planned in the area under examination, with different objectives depending on the project/plan that envisaged them. The prescriptions and interventions envisaged by the Life Granatha project⁴ and by the forest fire prevention plan "Piano Specifico di Prevenzione del Pratomagno" (PSP - Specific prevention plan here after), are being implemented.

The aim of the Life Granatha project is to restore the habitats of certain protected species identified by the Birds Directive (Directive 79/409/EEC). The project envisaged an intervention area of 1.7% (117 ha) of the SCI surface. The interventions foreseen by the Life project are: i) total elimination of the shrub layer (through mechanical clearing or the use of prescribed fire); ii) gaps cutting of the shrub layer (through

³ <https://land.copernicus.eu/en/products/corine-land-cover/clc2018>

⁴ <https://www.lifegranatha.eu/>

manual/mechanical clearing or the use of prescribed fire); iii) cutting of the shrub layer and pile-burning of the residues.

The interventions foreseen in the fire plan were planned with a civil protection purpose. The PSP covers 6% of the territory examined by the case study and the planned interventions cover 4.5% (65 ha) of the planned territory. The infrastructures envisaged by the PHP are: i) fuelbreaks; ii) fuelbreaks to protect the urban-rural interface; iii) Strategic Management Points.

Fuelbreaks in the region of Tuscany are infrastructures that support active firefighting to make firefighting operations safe and effective. These linear infrastructures modify the flammability of fuel to generate a change in fire behaviour and create an extinguishing opportunity for operators. Fuelbreaks are characterised by the reduction/elimination of the shrub layer within a buffer of 12-15 m around the roadway, selective thinning of the tree layer for an additional 30 m strip, removal of dying/dead trees and accumulations of deadwood on the ground. Possible chipping of residues.

Infrastructures protecting the urban-rural interface include the interface between the built-up areas and the forest, cultivated areas/shrublands/vegetation encroachment. These intervention areas aim to protect people, activities and man-made infrastructures by modifying the structure of the neighbouring vegetation to decrease the probability of fire and increase the effectiveness of fire-fighting operations. Fuelbreaks include the total removal of the shrub layer in a 25 m buffer from the urban area, together with the removal of maritime pine, dead or decaying trees and accumulations of deadwood on the ground. Possible chipping of residues.

Strategic Management Points are interventions affecting small areas but localised at points where the flame front divides and multiplies due to the morphology of the territory. These points are defined as "impluvial nodes" or "ridge nodes" depending on the morphological element that causes the flame front to multiply. The aim of Strategic Management Points is to avoid the multiplication of fire trajectories and, therefore, the possibility of a large fire occurring, and at the same time decrease the intensity of the flame front, making extinguishing activities safer and more effective. The Strategic Management Points include the following interventions: removal of most of the shrub layer (maximum release of 10-20%), selective thinning of the tree layer (25-40% removal), removal of dead/dead trees and accumulations of deadwood on the ground. Possible chipping of residues.

Thus, in total, business-as-usual interventions comprising both Life Granatha and Specific Prevention Plan interventions (shown in **Figure 16**) affect 1 % of the total area of the study area.

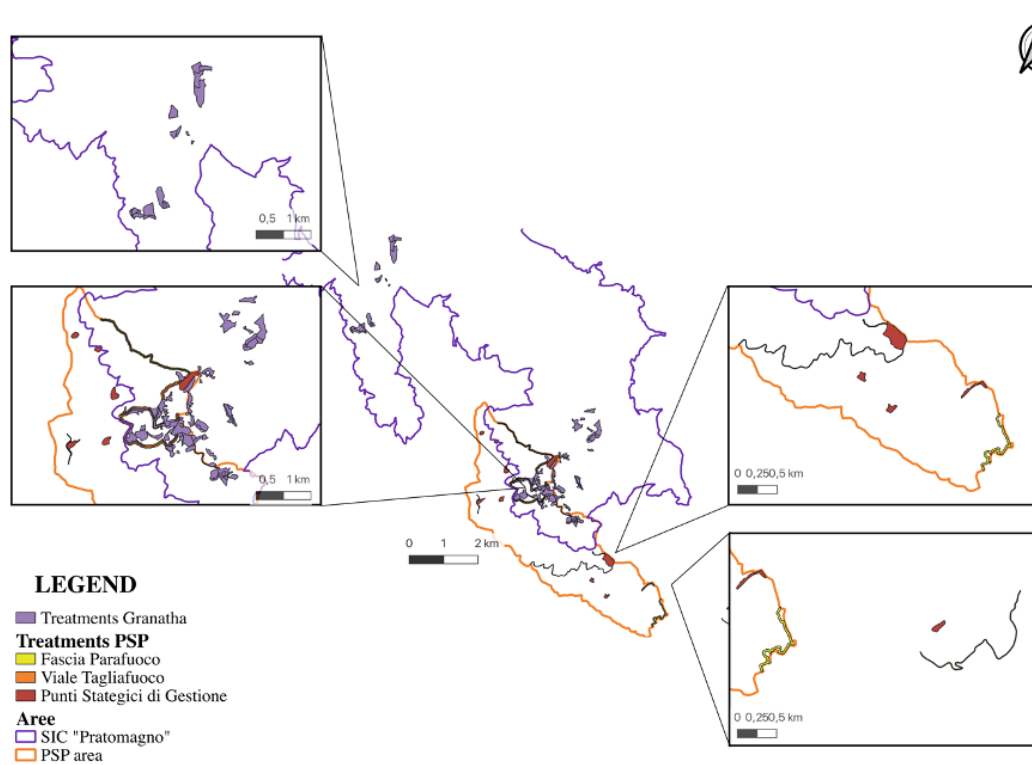


Figure 16 - Interventions envisaged by the Life Granatha project and the FIREFIGHTING Specific Prevention Plan.

3.2.5. Analysis of historical fires

In the last 16 years (2007-2023), 476 fires have occurred in the study area, covering an area of 690.5 ha (Figure 17).

HISTORICAL WILDFIRES

LEGEND

- Historical wildfires
- SIC "Pratomagno"
- Study area

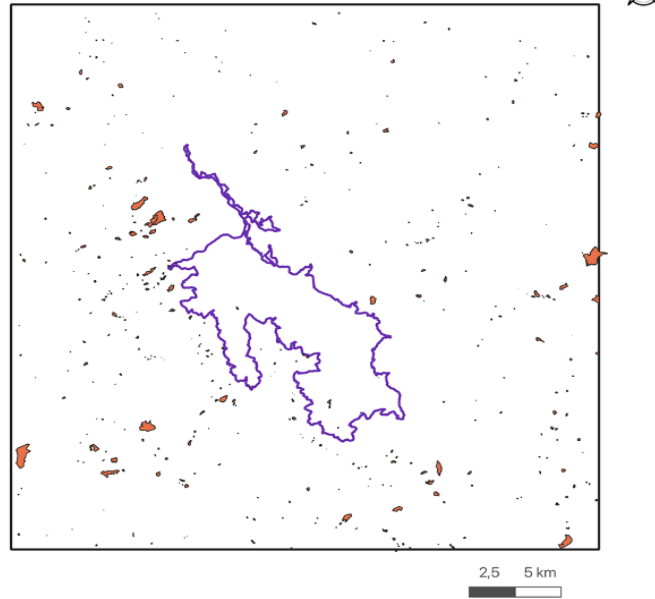


Figure 17 - Historical fires occurred in the study area in the period 2007-2023.

The average annual number of occurrences is 28, while the average annual area burnt by fires is 40.7 ha. The average area burned by each event is 1.2 ha. In the study area the number of small fires has been very high (e.g. 2017, 2021) (**Figure 18**) and, periodically, there have been years predisposing to fires where the annual area burned was particularly high: in 2012 the largest fire occurred (62.5 ha) (**Figure 19**).

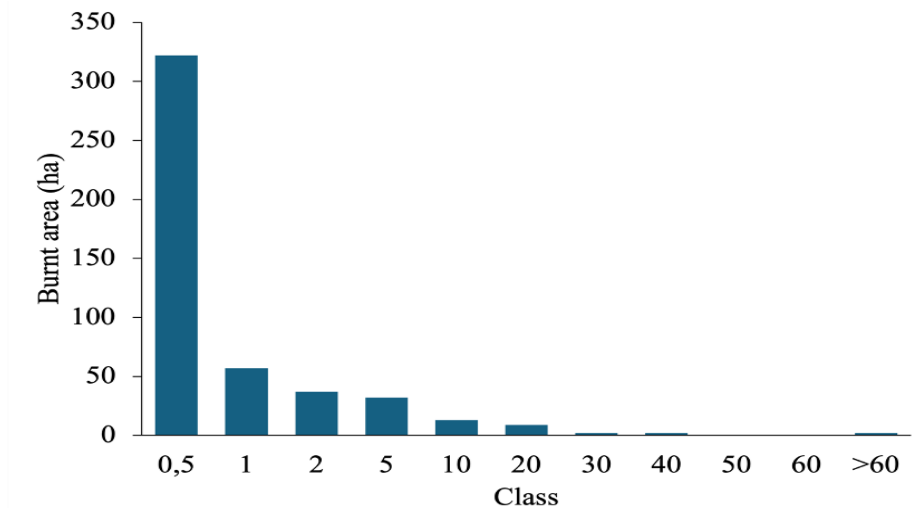


Figure 18 - Size class distribution of the area covered by fires in the study area.

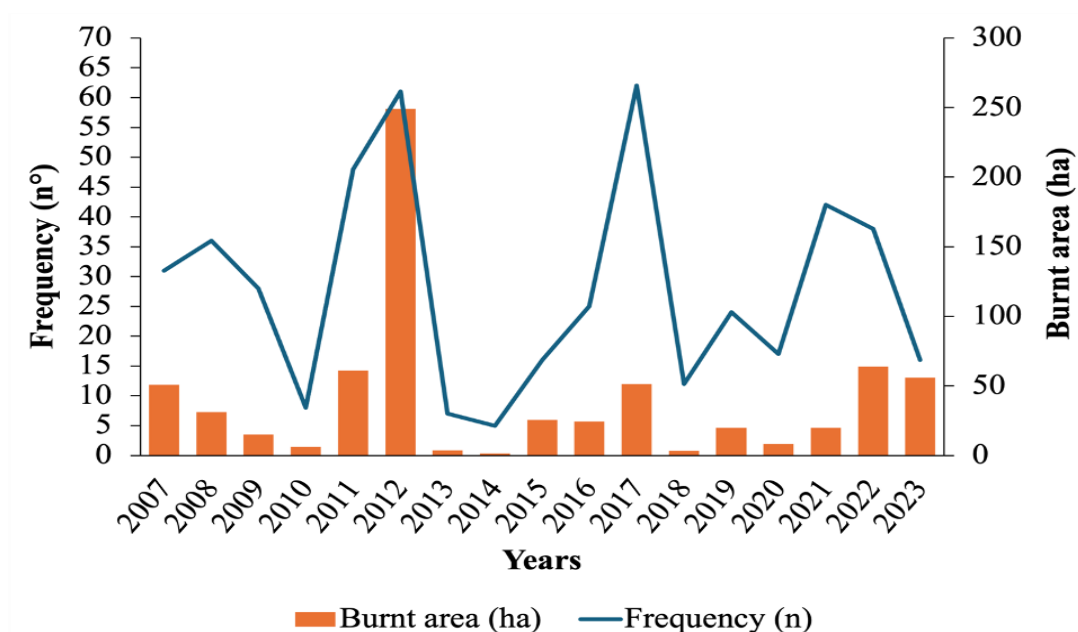


Figure 19 - Frequency distribution of fires and total annual area burnt in the study area, period 2007-2023.

A percentage of 1.6 % (4.3 ha) of historical wildfires affected the RN2000 site area. The fires that occurred were small and concentrated in the summer period (August) (**Table 19**). The target habitat (9260) within the SCI was affected by historical fires amounting to an area of about 0.05 ha.

Table 19 - Fires occurring within the 'Pratomagno' SCI in the period 2007-2023

Year	Burnt area (ha)	Dates
2008	0.4	04/09/08
2011	2.6	23/08/11
2011	0.1	30/08/11
2012	0.1	27/03/12
2014	0.1	27/08/14
2017	<0.1	20/08/17
2019	0.8	18/02/19
2021	0.3	16/04/21

3.2.6. Pre- and Post- planned treatments, Burn Probability (BAU) and TOM application

Figure 20 shows the distribution of the interventions foreseen by the planning in force in the Pratomagno PSP (**Figure 20A** - Treatments BAU - polygons in yellow) and the distribution of treatment opportunities where fire prevention interventions can be placed for the different objectives (**Figure 20B** - Treatment opportunities - polygons in grey). The application of the TOM model made it possible to spatialise fire prevention interventions with a civil protection objective (**Figure 20C** - TOM BAU optimised - polygons in

blue). **Figure 20D** compares the distribution of interventions foreseen by the current planning (in yellow) and their optimised spatialisation (in blue).

Figure 21 it can be observed how the optimised spatialisation of interventions (TOM BAU optimised) intercepts the preferential propagation trajectories that originate from a selection of trigger points extracted from the initial 5000 points (using hexagonal cells as extraction units) and that give rise to large fires (see **section 3.1.4**).

Figure 22 shows the analysis of the probability of fires occurring in the scenario in the absence of preventive interventions (PRE scenario), in the presence of the interventions planned by the Pratomagno Specific Prevention Plan (BAU scenario) and following the optimised spatialisation of preventive infrastructures using the TOM (optimised BAU scenario).

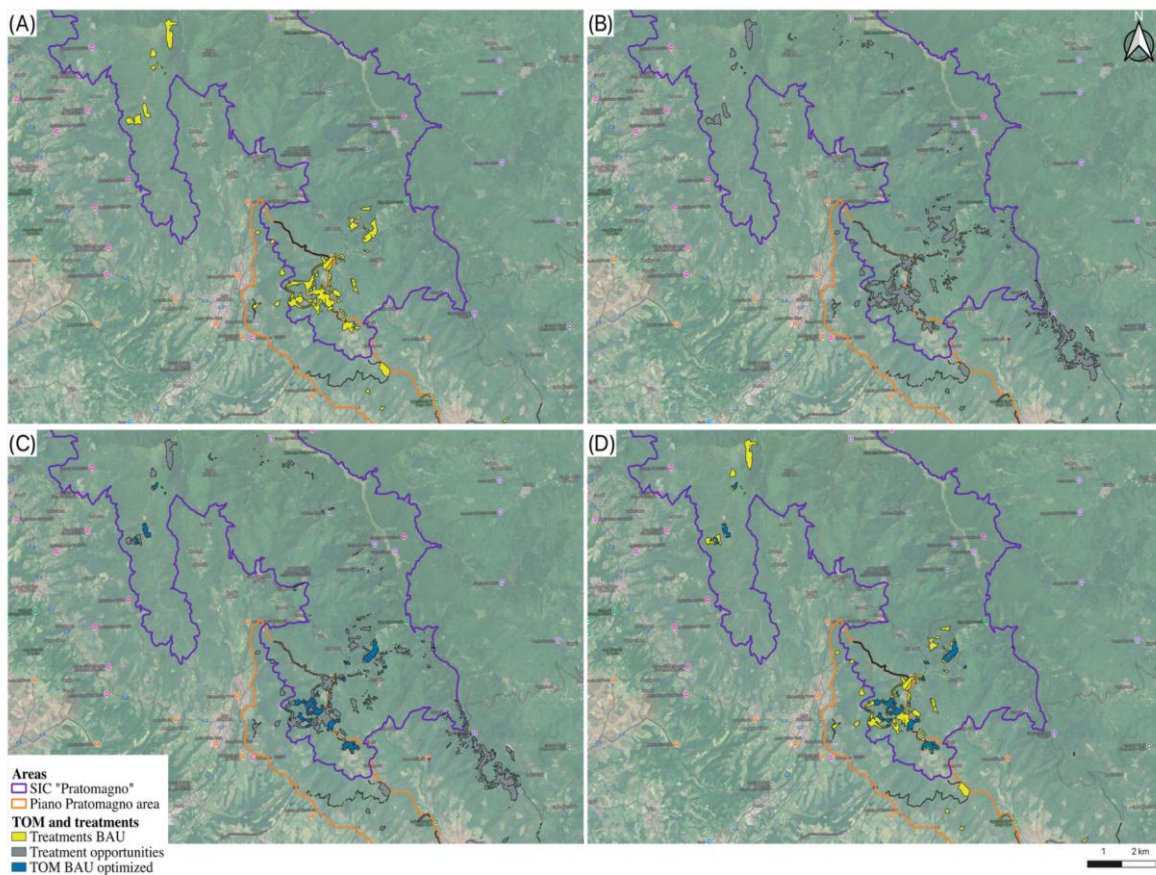


Figure 20 – (A) Interventions foreseen by the planning in force (PSP Pratomagno); (B) Treatment opportunities where fire prevention interventions can be placed for the different objectives; (C) optimised spatialisation of fire prevention interventions with a civil protection objective; (D) comparison between the interventions foreseen by the planning in force and their optimised spatialisation.

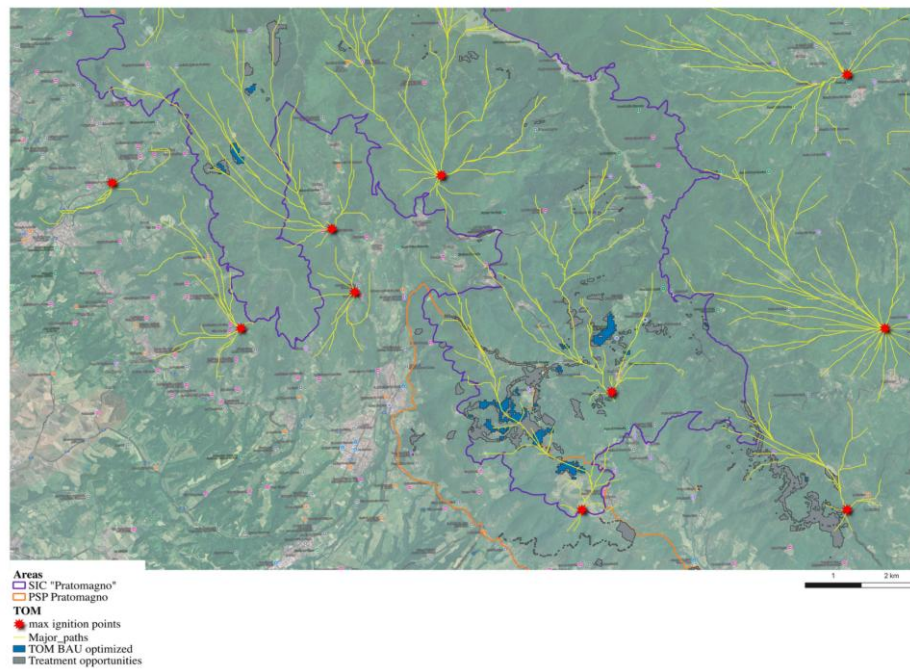
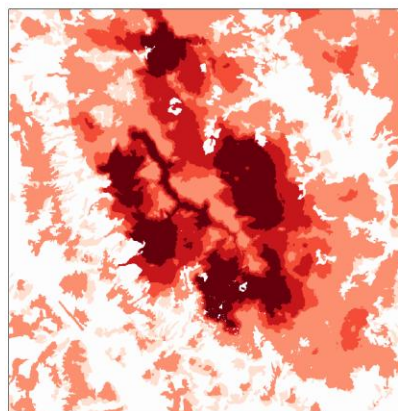
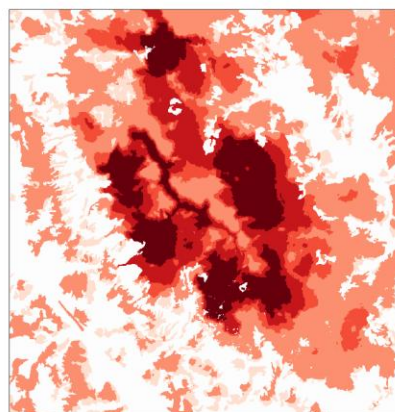


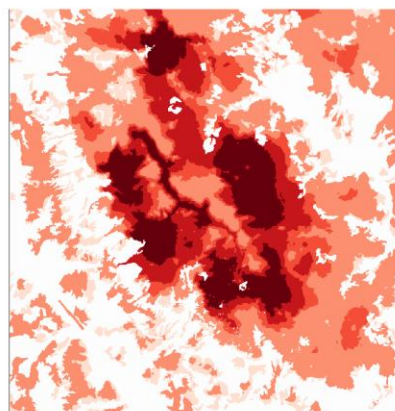
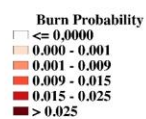
Figure 21 - Optimised spatialisation of fire prevention interventions with a civil protection objective.



scenario PRE



scenario BAU



scenario BAU optimized

2.5 5 km

Figure 22 - Burn Probability in the scenario in the absence of fire prevention interventions (PRE), after implementation of planned interventions (BAU) and after spatial optimisation of interventions with a civil protection objective (BAU optimised).

3.2.7. Proposed Spatialisation of Biodiversity Protection Interventions and Calculation of Post-Intervention Burn Probability

The **Figure 23** shows the distribution of treatment opportunities, where fire prevention interventions can be placed for the different objectives (Treatment opportunities - polygons in grey), and the application of the TOM model, which made it possible to spatialise fire prevention interventions with the objective of conserving biodiversity (TOM BIO - polygons in green). It can be seen how the optimised spatialisation of the interventions (TOM BIO) intercepts the preferential propagation trajectories originating from the ignition point (max ignition point BIO). This ignition point was selected from among the ignition points that originate large fires within the landscape and is responsible for the large fire that would intercept or influence the CA and IB (see **Section 3.1.6**).

Figure 24 shows the fire probability analysis in the scenario without preventive interventions (PRE scenario) and following the optimised spatialisation of preventive infrastructures with the objective of biodiversity conservation using the TOM (BIO scenario).

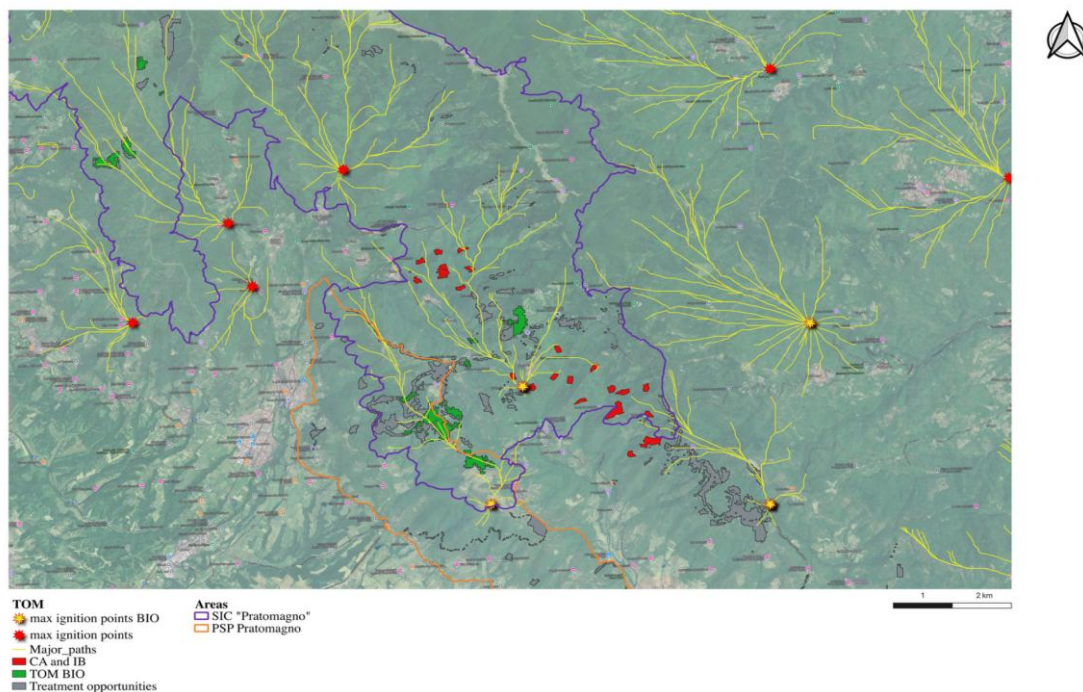


Figure 23 - Optimised spatialisation of fire prevention interventions with the objective of biodiversity conservation.

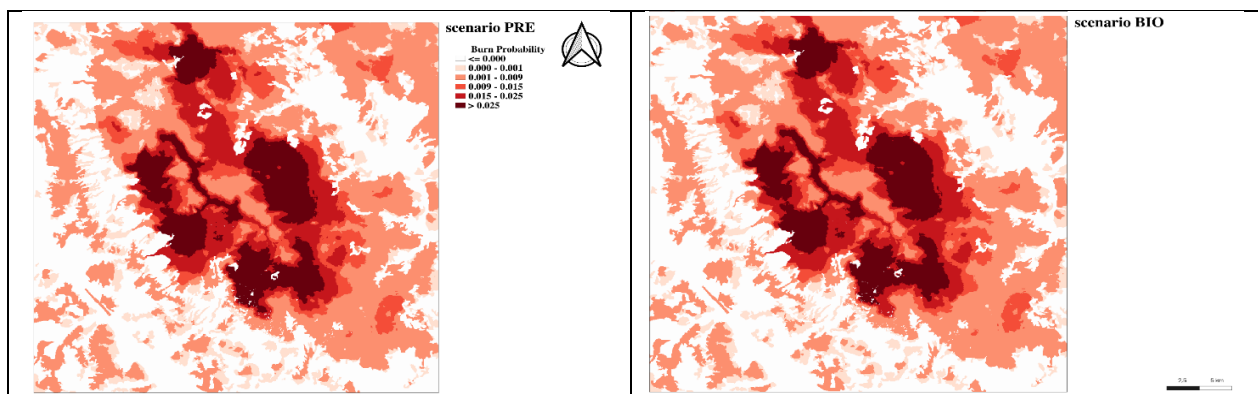


Figure 24 - Burn Probability in the scenario without fire prevention interventions (PRE) and after spatial optimisation of interventions with the objective of biodiversity conservation (BIO).

3.2.8. Proposed spatialisation of interventions to achieve the trade-off of areas to be treated for the achievement of civil protection and biodiversity conservation objectives

Figure 25 shows the distribution of treatment opportunities where fire prevention interventions can be placed for the different objectives (**Figure 25A** - Treatment opportunities - polygons in grey). The application of the TOM model made it possible to spatialise fire prevention interventions with a civil protection objective (**Figure 25B** - TOM BAU optimised - polygons in blue) and with a biodiversity conservation objective (**Figure 25C** - TOM BIO - polygons in green). **Figure 25D** shows the trade-off in the distribution of the areas of fire prevention interventions to achieve both the civil protection and biodiversity conservation objectives (TOM TRADE-OFF - polygons in pink).

Figure 26 shows the fire probability analysis in the scenario with no preventive intervention (PRE scenario) and following the optimised spatialisation of preventive infrastructure using the TOM to achieve both objectives (TRADE-OFF scenario).

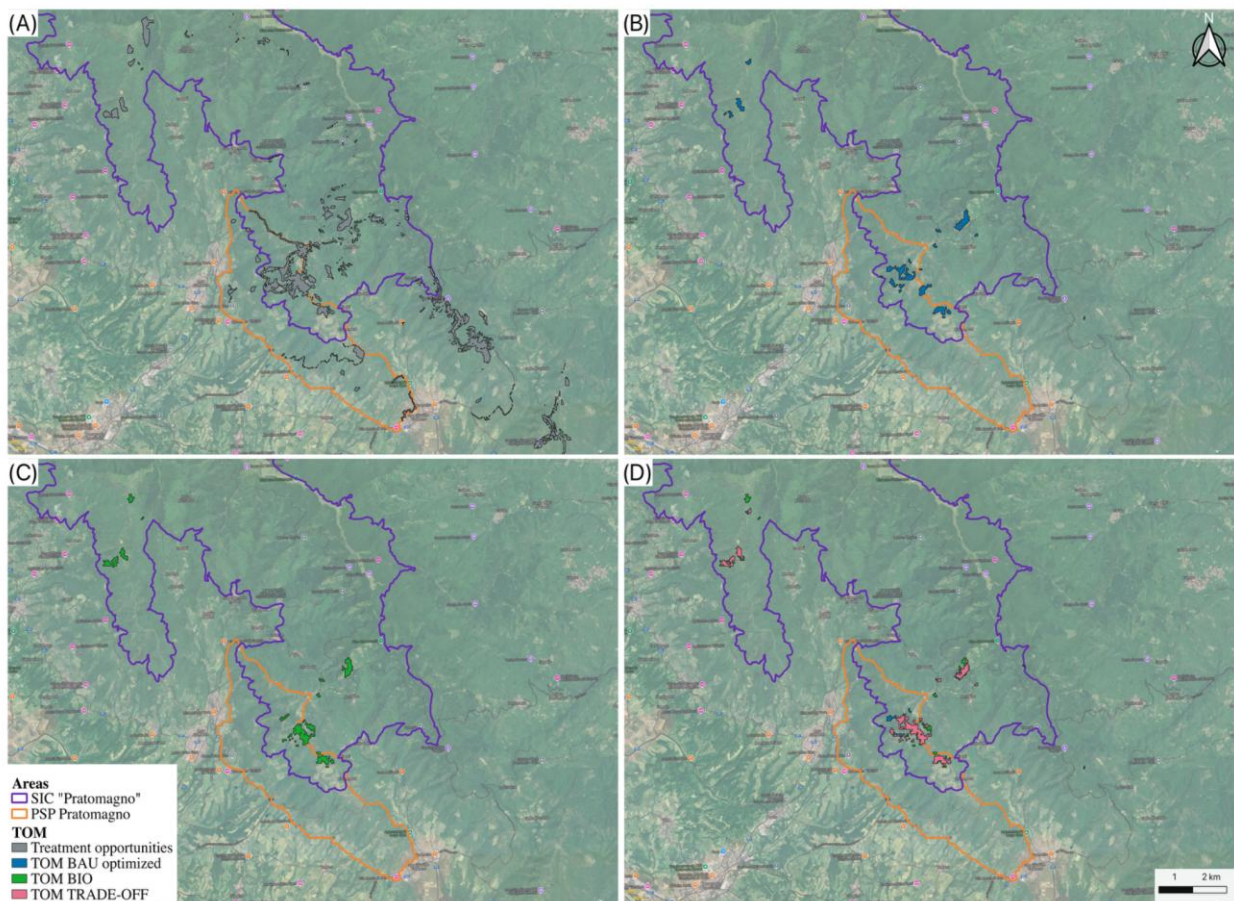


Figure 25 - (A) Treatment opportunities where fire prevention interventions can be placed for the different objectives; (B) optimised spatialisation of fire prevention interventions with civil protection objective; (C) optimised spatialisation of fire prevention interventions with biodiversity conservation objective; (D) trade-off of intervention areas to achieve both civil protection and biodiversity conservation objectives.

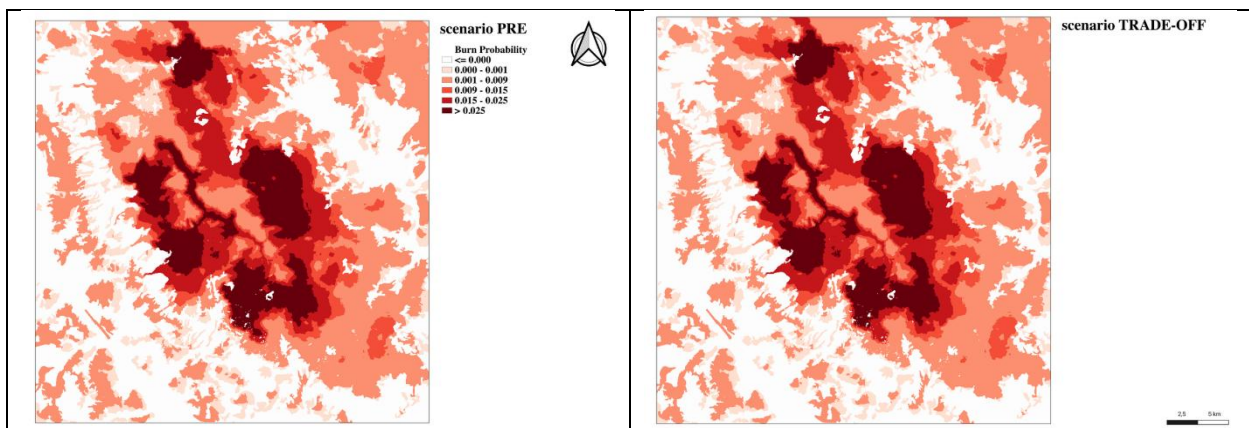


Figure 26 - Burn Probability in the scenario without fire prevention interventions (PRE) and the implementation of the interventions on the areas identified by the Treatment Optimisation Model as the areas that allow both civil protection and biodiversity conservation objectives to be met (TRADE-OFF).

3.2.9. Evaluation of the variation in the probability of fires occurring and the distribution of potential fires in different spatialisation scenarios of fire prevention interventions

Figure 27 shows the map of fire risk in the absence of fire prevention interventions (risk PRE). This map was created using a matrix combining the hazard classes in absence of preventive infrastructure (Hazard PRE, **section 3.1.1**) and the potential impact (Potential impact, **section 3.1.2**) (**Figure 28**).

Table 20, for the landscape areas falling in the Very High-risk class, the difference (delta) between the average probability of travel in the scenario without fire prevention interventions (PRE) and in the scenarios of optimised fire prevention interventions with a civil protection objective (BAU opt), of biodiversity conservation (BIO) and of trade-off of areas between the two objectives (TRADE-OFF) was calculated. The ratio between the delta between the PRE scenario and the optimised BAU scenario (delta PRE-BAUopt) and the delta between the PRE scenario and the BIO scenario (delta PRE-BIO) and the TRADE-OFF scenario (delta PRE-TRADE-OFF) shows how the difference between the optimised BAU and BIO scenarios in the reduction of Burn Probability is negligible (1.0 %), while the reduction in the probability of a fire passing is 17.0 % greater in the TRADE-OFF scenario than in the optimised BAU scenario. These results highlight the expected effectiveness in reducing burn probability of spatialisation of interventions with a civil protection objective, but also a greater effectiveness in reducing burn probability through the trade-off of areas dedicated to the construction of fire prevention infrastructure to achieve both objectives.

Table 21, for each exposure, the difference (delta) between the average travel probability in the scenario with no fire prevention interventions (PRE) and in the scenarios of optimised fire prevention interventions with civil protection objective (BAU opt), biodiversity conservation (BIO) and area trade-off between the two objectives (TRADE-OFF) was calculated. The relationship between the delta between the PRE scenario and the optimised BAU scenario (delta PRE-BAUopt) and the delta between the PRE scenario and the BIO scenario (delta PRE-BIO) and the TRADE-OFF scenario (delta PRE-TRADE-OFF) shows how the optimised BAU scenario leads to greater Burn Probability reduction than the BIO scenario for the biodiversity (Biodiversity, reduction of 6.8 %), habitat (Habitat, reduction of 8.0 %) and civil protection (Urban-wilderness Interface, reduction of 5.6 %), while for the biomass-carbon stock exposures (Forest Ecosystem Services) and soil protection (Soil erosion) there is a greater Burn Probability reduction in the BIO scenario of 2.4 and 2.8 % respectively. The greatest reduction in Burn Probability was observed in the TRADE-OFF scenario (average BP reduction greater than $14.8 \pm 8\%$ compared to the optimised BAU scenario) for all exposures.

These results again emphasise the expected effectiveness in reducing the probability of travel of the spatialisation of interventions with a civil protection objective for the majority of exposures, but above all a greater effectiveness in reducing the probability of travel through the trade-off of the areas dedicated to the construction of fire prevention infrastructures to achieve both objectives (**Table 21**).

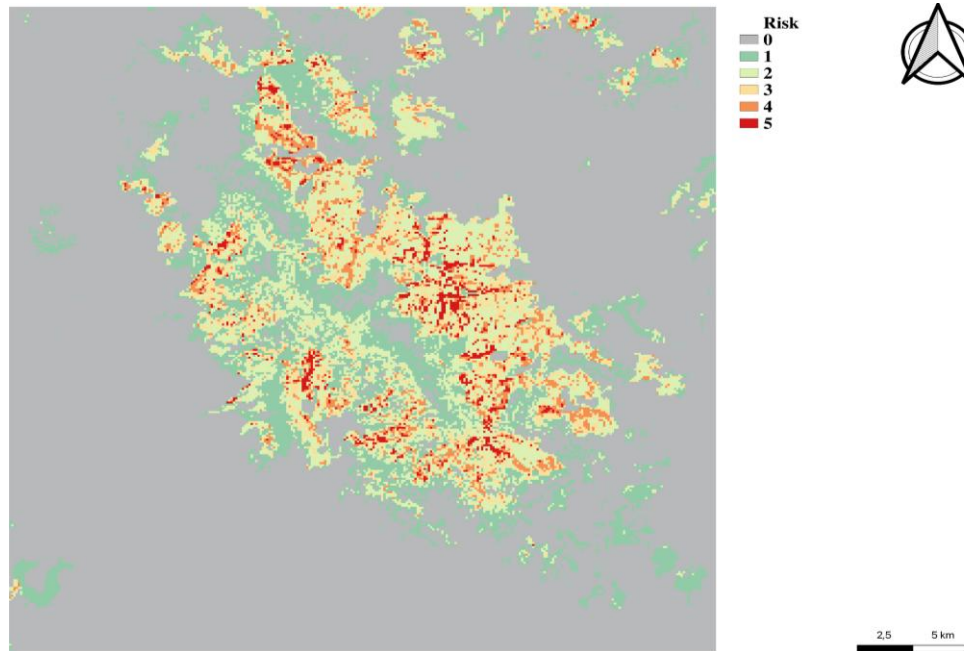


Figure 27 - Fire risk in the absence of fire prevention measures (risk PRE) divided into classes.

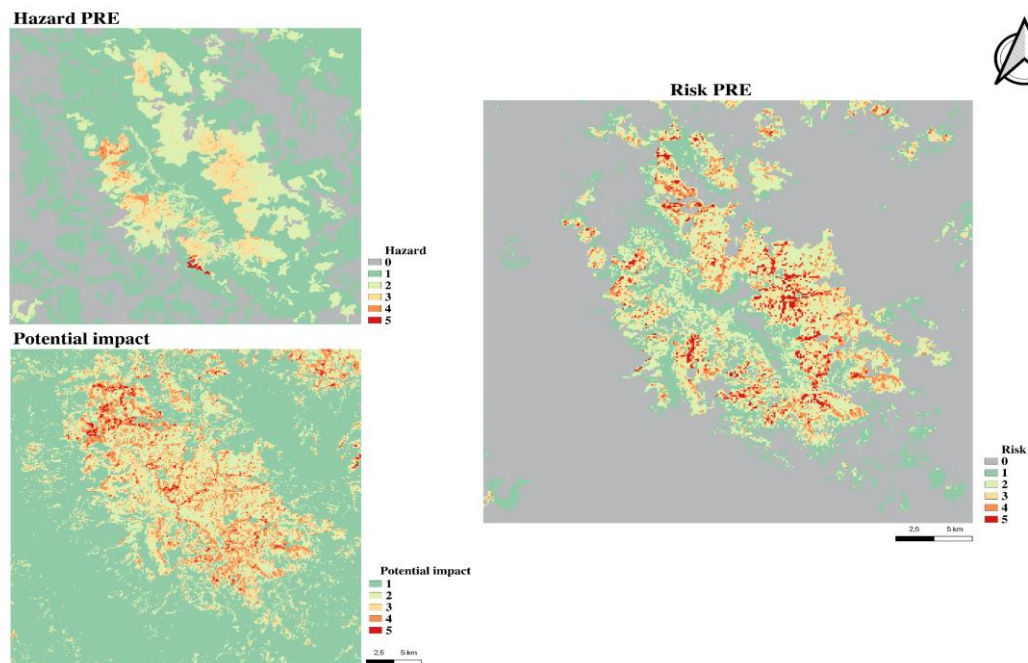


Figure 28 - Hazard in the absence of preventive infrastructure (Hazard PRE), Potential impact (Potential impact) and Fire risk in the absence of fire prevention measures (Risk PRE) divided into classes.

Table 20 - Delta: difference between the average Burn Probability in the scenario without fire prevention interventions (PRE) and in the optimised BAU scenario (BAUopt), BIO and TRADE-OFF for the landscape areas in fire risk class Very High; Delta ratios: ratio between the delta of Burn Probability PRE-BAU optimised (BAUopt) and the deltas of Burn Probability PRE-BIO and PRE-TRADE-OFF for the landscape areas in fire risk class Very High.

Delta		
PRE-BAUopt	PRE-BIO	PRE-TRADEOFF
0.000202	0.000199	0.000243
Rapporti dei delta		
deltaPRE-BAUopt/ deltaPRE-BIO	deltaPRE-BAUopt/ deltaPRE-TRADEOFF	
1.017768	0.831689	

Table 21 - Delta: Difference between the average Burn Probability in the scenario without fire prevention interventions (PRE) and in the scenario BAU optimised (BAUopt), BIO and TRADE-OFF for each exposure; Delta ratios: ratio between the delta of Burn Probability PRE-BIO and PRE-TRADE-OFF for each exposure.

	Delta			Rapporti dei delta	
	PRE-BAUopt	PRE-BIO	PRE-TRADE-OFF	deltaPREBAUopt/ deltaPREBIO	deltaPREBAUopt/ deltaPRETRADE-OFF
Biodiversity	0.000773	0.00083	0.000955	0.931543	0.809854
Habitat	6.23E-05	6.77E-05	7.8E-05	0.919988	0.79877
Forest Ecosystem Services	5.62E-05	5.48E-05	5.87E-05	1.024818	0.957055
Soil Erosion	9.91E-05	9.64E-05	0.000108	1.028325	0.917515
Urban-wilderness Interface	5.29E-05	5.61E-05	6.81E-05	0.943201	0.776663

Figure 29 shows the distribution of simulated potential fires in the different size classes for each scenario. Differences were found above all in size classes 9 to 12, i.e. for fires from 100 to 1000 ha, where there was an increase in the frequency of potential fires in classes 9 to 11 respectively: 2.5 ± 2.6 % in the BAU scenario, 0.6 ± 0.2 % in the optimised BAU scenario (BAU opt), 0.7 ± 0.5 % in the BIO scenario and 0.8 ± 0.7 % in the TRADE-OFF scenario (Table 22). On the other hand, in size class 12 (range: 500-1000 ha) there was an average decrease in the frequency of potential fires of 1.6 ± 1.4 %. These results underline how the greatest effectiveness in reducing the size of potential fires was obtained with the optimised spatialisation of interventions with a civil protection objective (optimised BAU scenario), followed by the trade-off of the areas dedicated to building fire prevention infrastructures to achieve both objectives (TRADE-OFF scenario) (Figure 30)

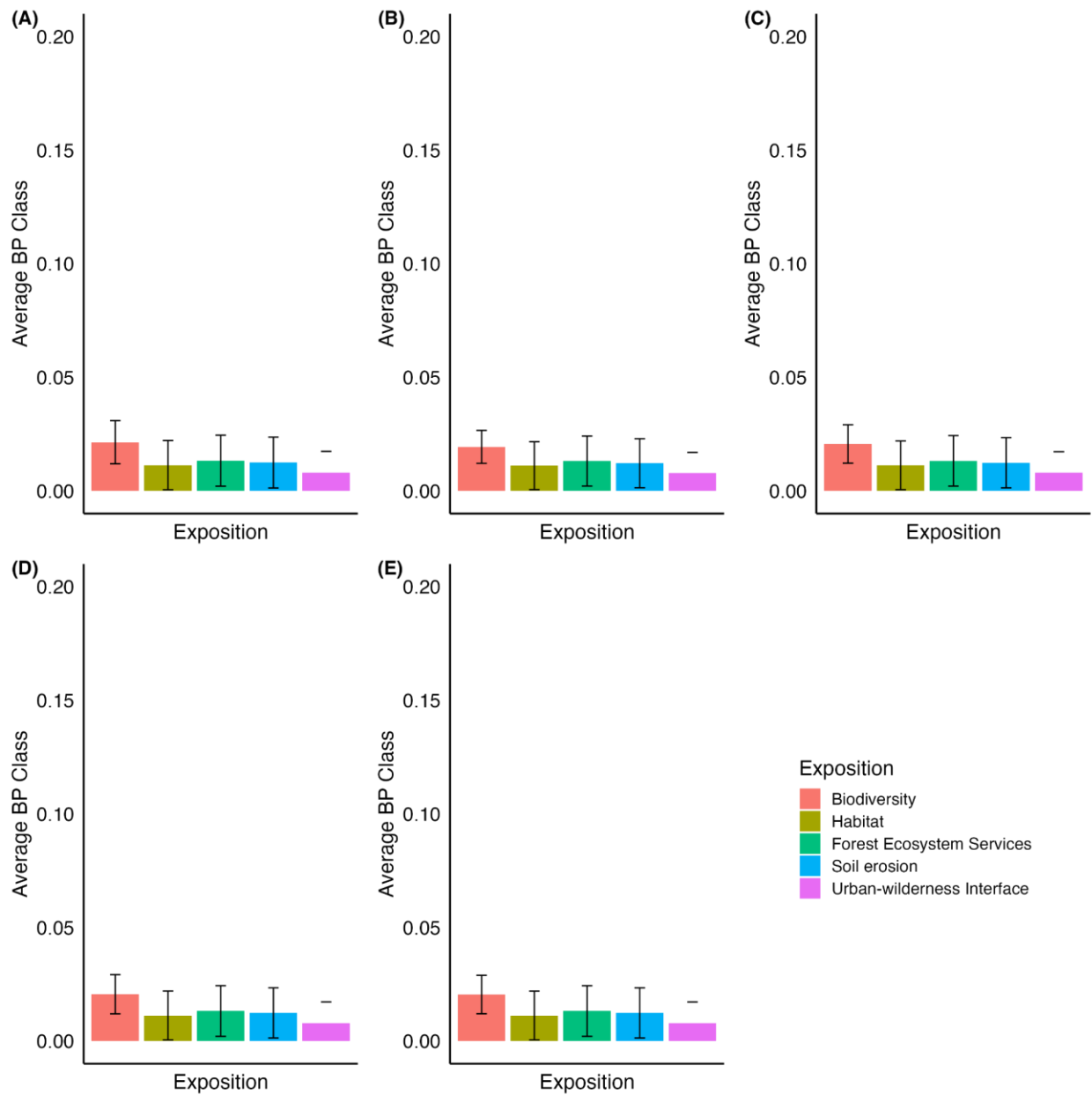


Figure 29 - Average Burn Probability ($\pm$ SD) in the exposures in the different fire prevention spatialisation scenarios: (A) PRE, (B) BAU, (C) optimised BAU, (D) BIO, (E) TRADE-OFF).

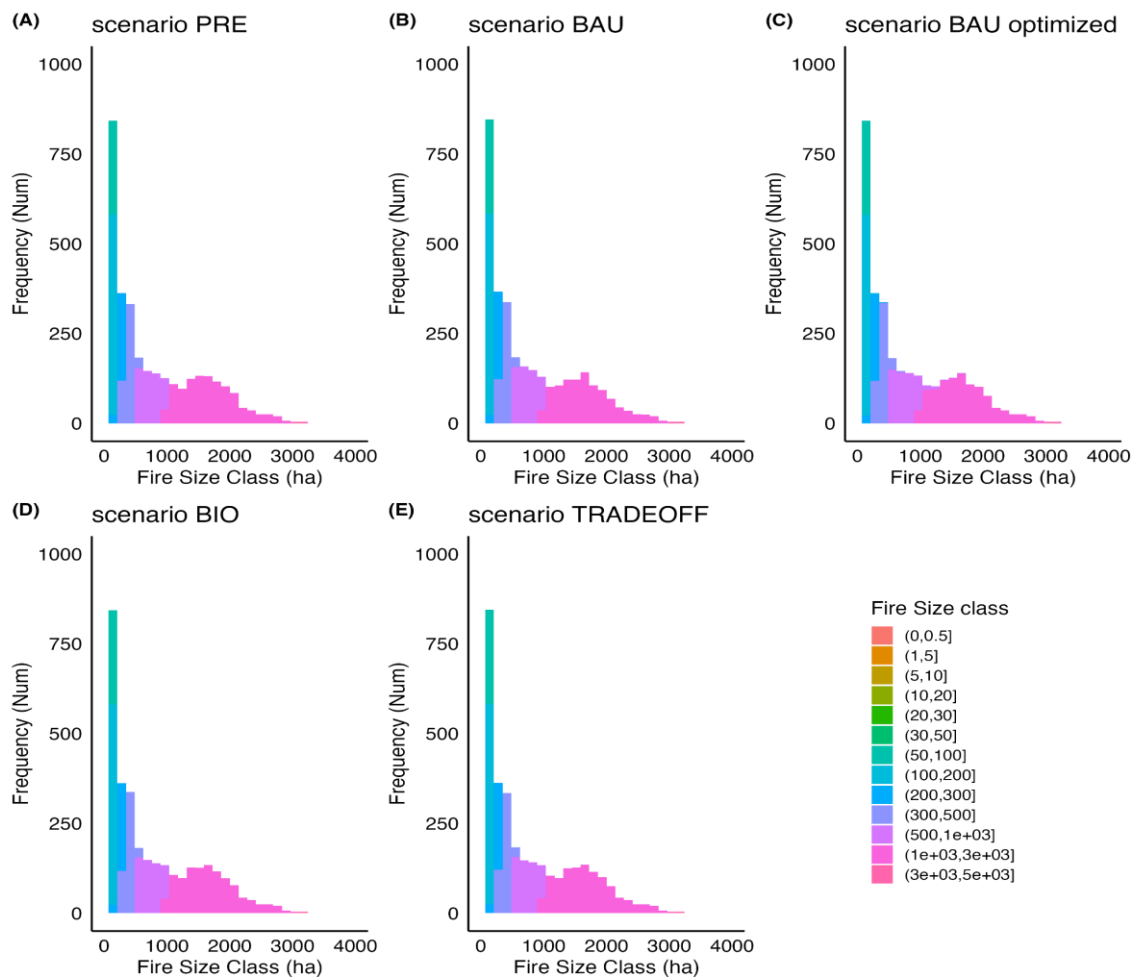


Figure 30 - Distribution in size classes of potential fires in the different fire prevention spatialisation scenarios: (A) PRE, (B) BAU, (C) BAU optimised, (D) BIO, (E) TRADE-OFF.

Table 22 - Relationship between the relative frequencies of potential fires in the different spatialisation scenarios of fire prevention interventions and the relative frequencies of potential fires in the scenario without fire prevention interventions (PRE) for each size class.

N Fire Size	Fire Size Class	Reports			
		BAU/PRE	BAUopt/PRE	BIO/PRE	TRADEOFF/
1	[0,0.5]	0.999201	1	1	1
2	[0.5,1]	1	1	1	1
3	[1,5]	1	1	1	1
4	[5,10]	1	1	1	1
5	[10,20]	1	1	1	1
6	[20,30]	1	1	1	1
7	[30,50]	1	1	1	1
8	[50,100]	1.005376	1	1	1
9	[100,200]	1.003759	1.003759	1.003759	1.003759
10	[200,300]	1.016667	1.00625	1.004167	1.004167
11	[300,500]	1.055028	1.00759	1.013283	1.017078
12	[500,1000]	0.963303	0.992661	0.990826	0.988991
13	[1000,3000]	1	1	1	1
14	[3000,5000]	0.999201	1	1	1

3.3. Analysis for the Prades site

3.3.1. Location and site description

The Natura 2000 Network Site "Muntanyes de Prades" (ES5140008) (hereinafter referred to as "Prades") is located in the North-East of Spain, Region of Catalonia, has an extension of 11788 ha and covers 20 municipalities in the counties of Priorat, Baix i Alt Camp and Conca del Barberà, in the province of Tarragona (**Figure31**). The study area is in the north-eastern part of the Site and has an extension of 19324 ha.

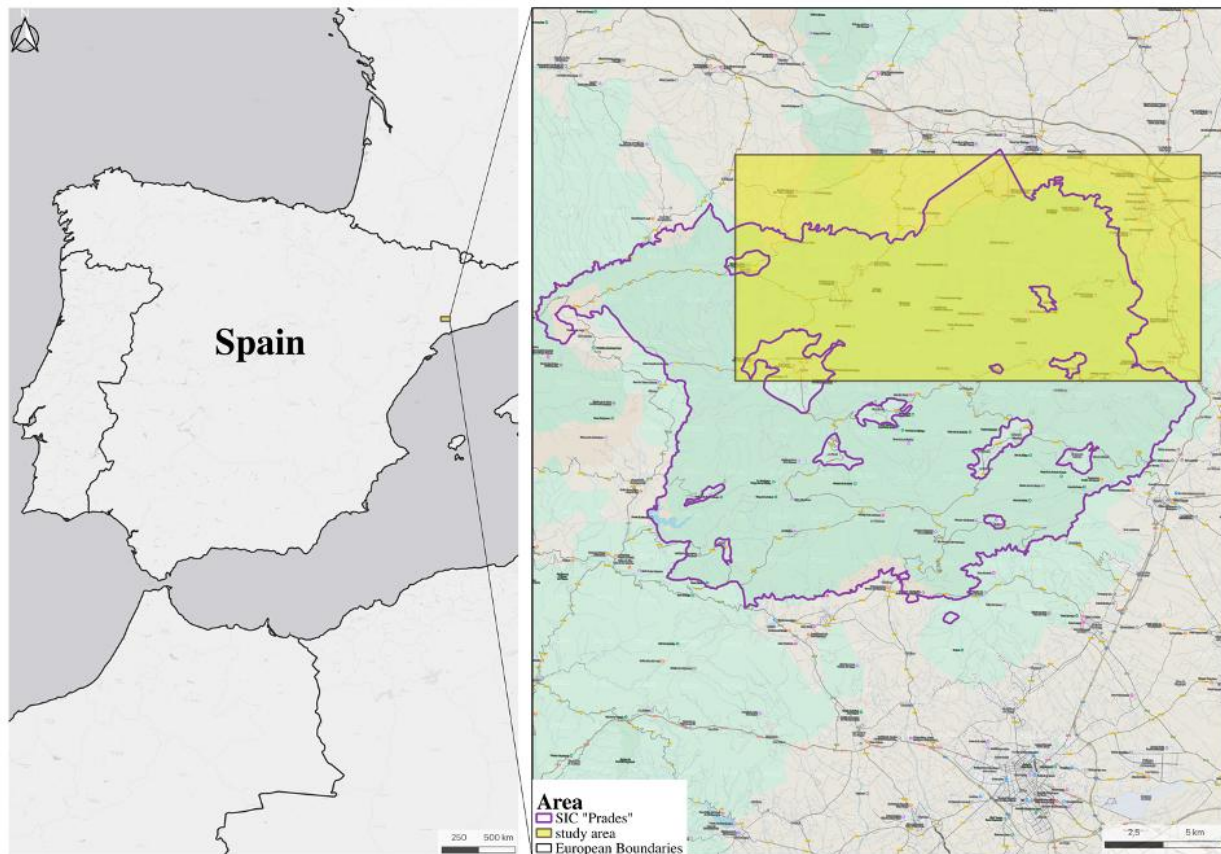


Figure31 - Location of the RN2000 Site 'Prades' and the Catalan study area.

The study area is characterised by an average elevation of 691 m above sea level, an average slope of 29 %, and a predominantly 168° exposure (**Figure32**); furthermore, on average, there is a high and continuous tree cover, especially in the Prades study area under consideration (**Figure 33**).

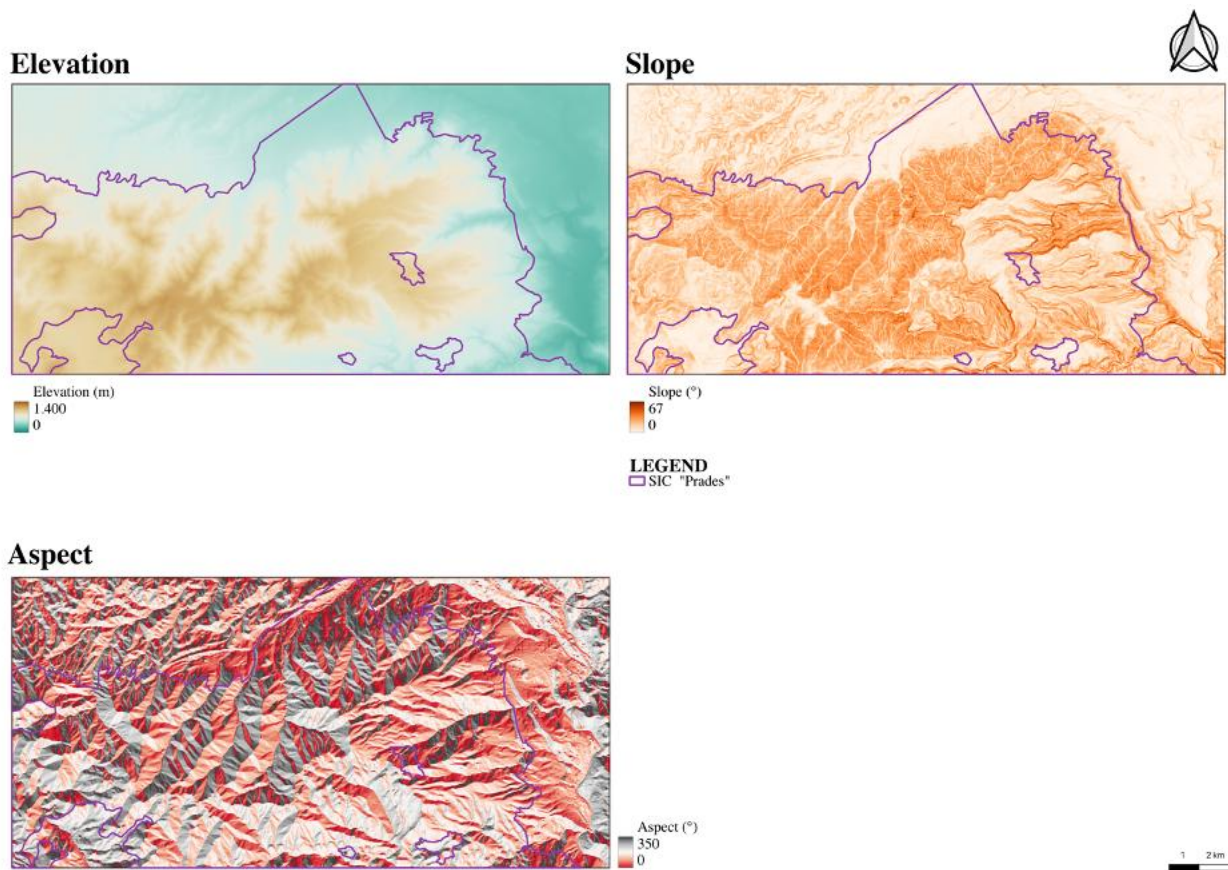


Figure32 - Cartographies of the morphological elements of the study area.

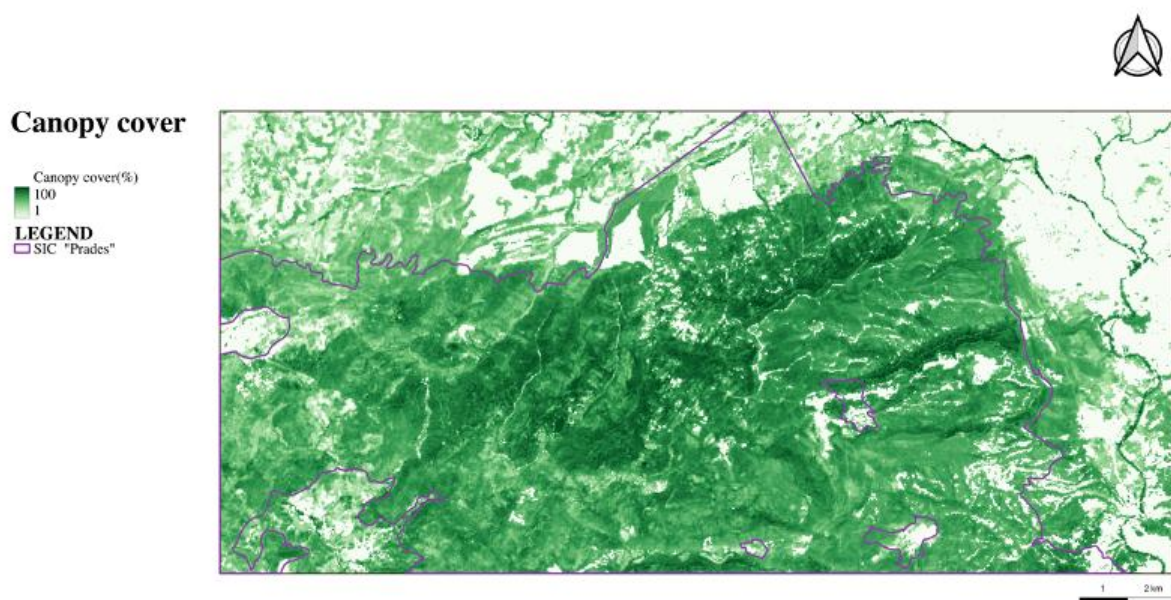


Figure 33 - Tree cover in the study area.

3.3.2. Biodiversity (sensitivity/adaptation, number/size/description of habitats present)

The habitats listed in Annex A are present in the study area. In particular, in the Prades Site, there is the priority Mediterranean habitat of the Natura 2000 Network, project target "Habitat 9350* - (sub)Mediterranean pine forests of endemic black pines (*Pinus nigra* subsp. *salzmannii*)"; within these areas the Core Areas (CA) and Islands of Biodiversity (IB), biodiversity conservation targets (Figure 34) have been identified by Task 3.1.

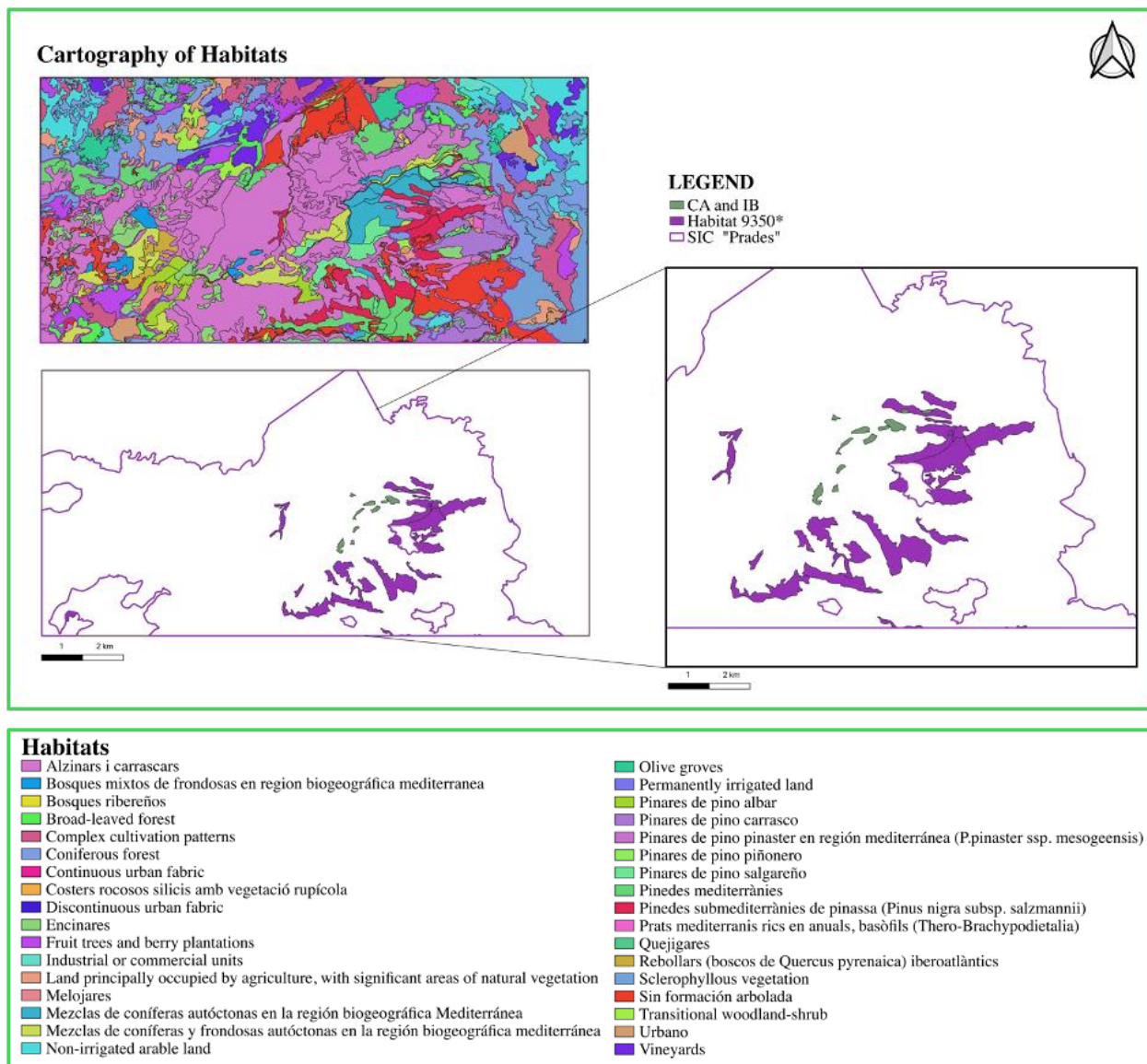


Figure 34 - Habitat map of the study area and related legend (left and bottom); habitat 9350* - (sub)Mediterranean endemic black pine forests (*Pinus nigra* subsp. *salzmannii*) and Core Area and Islands of Biodiversity in the study area (right).

The habitat 9350* - (sub)Mediterranean (sub)pine forests of endemic black pines (*Pinus nigra* subsp. *salzmannii*) - covers an area of 3% of the study area (589 ha), while the biodiversity conservation objectives (CA and IoS) amount to 0.2% (39 ha). The most widespread habitat within the study area is *Quercus ilex* and *Quercus rotundifolia* forests (alzinars i carrascars), covering an area of 5964 ha (30.8% of the study area) (Figure 35), followed by coniferous forests (8% of the study area). The most extensive habitat within the SCI is *Quercus ilex* and *Quercus rotundifolia* forests (alzinars i carrascars) (50 % of the SCI).

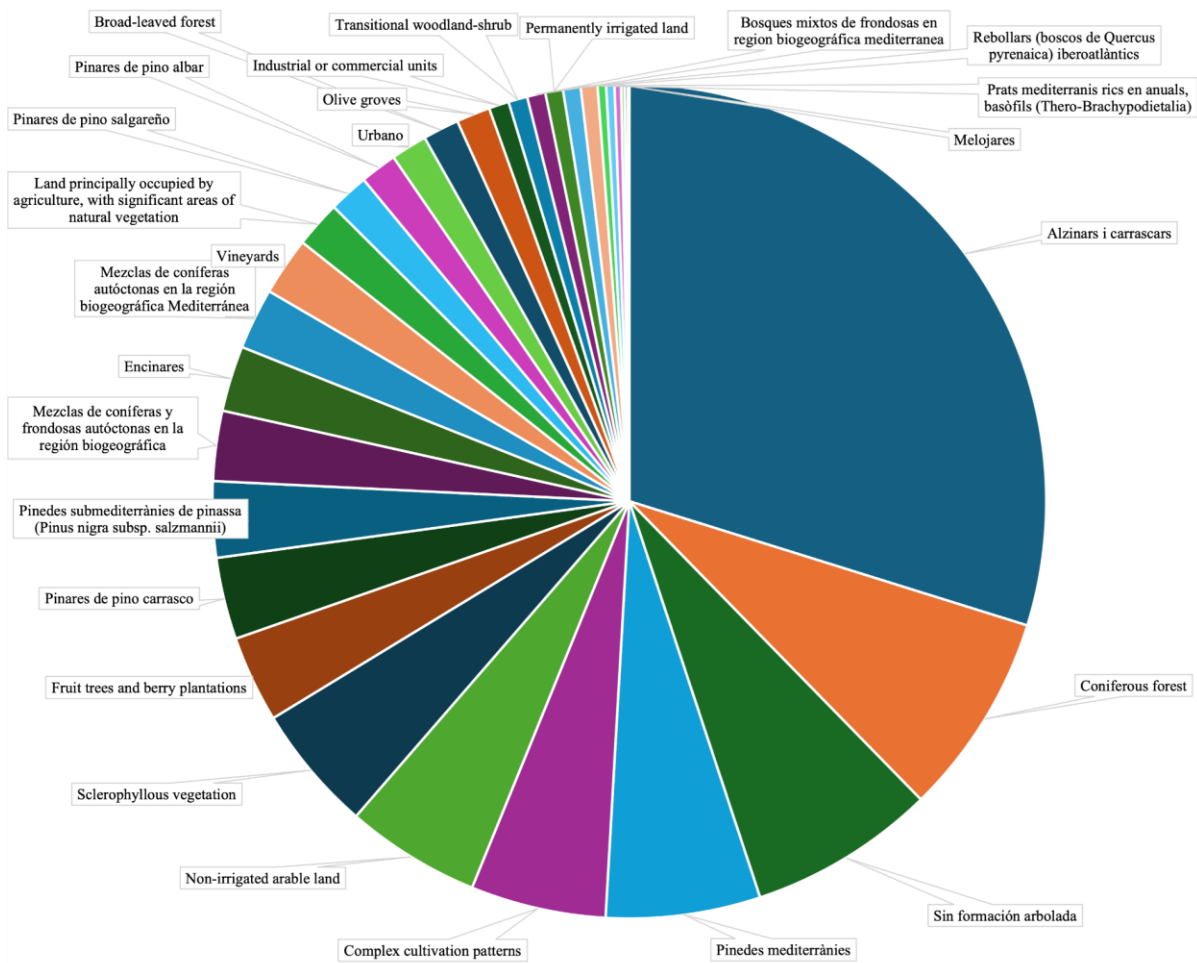


Figure 35 - Surface areas of habitats in the study area.

3.3.3. Fuel models map

Starting from the mapping of forest formations and the LiDAR data of the PNOA, the Forest Science and Technology Centre of Catalonia (CTFC) developed the fuel model map of PPP T3 (**Figure 36**). In the area surrounding the perimeter of PPP T3, a fuel model was assigned to agricultural areas that considers the most unfavourable situation for fire propagation (model 181), while model 161 was assigned to Mediterranean pine forests.

The fuel models with the greatest presence in the study area are model 147 and model 165. The area occupied by these models represents 41% of the surface area of the study area.

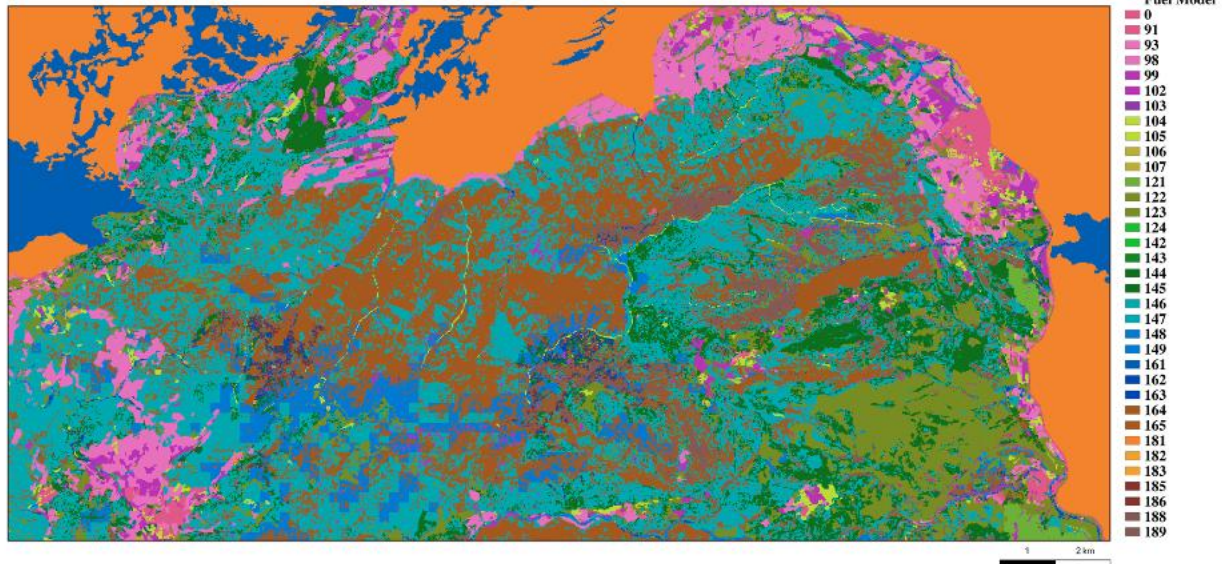


Figure 36 - Fuel model map, FlamMap input.

3.3.4. Types of interventions

At present, the territory under consideration is planned by the 'Projecte d'infraestructures estratègiques i bàsiques de prevenció d'incendis forestals' territorial plan that includes the "Perímetre de Protecció Prioritària Massís de les Muntanyes de Prades-Bosc de Poblet (PPP T3)", which overlaps almost entirely with the area of the 'Prades' SCI.

The Plan provided for the identification of areas for fire prevention with a civil protection objective on the entire territory of the PPP de les Muntanyes de Prades-Bosc de Poblet. Two types of areas were identified:

- A strategic management point (PEG) is an area dedicated to fire prevention that aims at the effectiveness and safety of firefighting operations. PEGs are part of the axes of discontinuity and seek to facilitate attack on both the flanks and the tail of the fire, to limit propagation to multiple potential polygons. It is an area associated with a specific strategy and tactic for a project fire and therefore sized according to extinguishing opportunities and critical points. They may include several facilities to support firefighting operations such as refuelling points, water points, roads. PEGs have the following technical characteristics:
- presence of a location point for vehicles with manoeuvring space;
- presence of an adjacent security area;
- presence of a strategic area with low vulnerability to crown fire;
- presence of a complementary area with moderate vulnerability to crown fire;
- presence of water points or hydrants on or within 20 minutes of the PEG itself;
- access to drainage points on primary, secondary or tertiary routes with crevasses of less than 300 m.

There are 33 PEGs present in the study area (of which 23 are in the SCI), covering an area of 297 ha (of which only 10 ha are outside the SCI), or 1.5 % of the study area (**Figure 37A**).

- Fire management zone (ZFG) is an area dedicated to fire prevention with the objective of reducing the vulnerability of agricultural, forest and heath systems to the passage of fire and increasing their resistance through the management of these areas. The ZFG is an area associated with the discontinuity axes of fire containment and of equal importance and priority to the PEGs.

ZFGs have the following technical characteristics:

- presence of areas with moderate vulnerability to crown fire;
- presence of security roads;
- presence of anchorages that can be identified by possible parallel or indirect routes of attack.

There are 13 GFAs in the study area (all in the SCI), covering an area of 485 ha (2.5 % of the study area) (**Figure 37A**).

Within the PEG and ZFG, the Plan provides for the following fire prevention infrastructure:

- strategic area: an intervention area located in PEGs whose objective is to change fire behaviour, i.e. to reduce the rate of spread, flame length or linear intensity;
- strategic auxiliary band: an intervention area located in the PEG and ZFG whose objective is to facilitate the attack on the flank and tail of the fire through the treatment of vegetation connected to a line of defence (road, path);
- complementary area: area of intervention associated with PEG and ZFG whose objective is to reduce the vulnerability of forest areas to fire and/or improve the effectiveness of strategic areas;
- safety area: area located within the PEGs consisting of shelter points for firefighting equipment in case of entrapment in the fire, water or hydrant points, path widening, flat areas, open areas (crops, pastures).

Within strategic areas, strategic auxiliary strips and complementary areas, the total or partial use of the shrub layer is envisaged, and the partial removal of the tree layer.

Within the safety areas, the total removal of the fuel load is planned, with the release of the herbaceous layer and part of the crop residues.

The details of the fire prevention interventions within the areas identified by the Plan are then established and implemented by the contracting forestry companies. The business-as-usual interventions were then selected by the Treatment Optimisation Model (TOM) module of the FlamMap application, using as inputs:

- Landscape file of current conditions, landscape PRE, representing current conditions without fire prevention interventions;
- Landscape ideal, generated by modifying the landscape PRE by assuming the implementation of fire prevention interventions within the areas identified by the Plan equal to 1% of the surface area of the study area, equal to the minimum treated surface area envisaged by the plans in force in the two case studies and representative of the number of resources available for fire prevention;
- Ignition points: 5000 ignition points spatialised over the study area using the criteria described above (**section 3.1.1**)

The TOM was run using the inputs described above to obtain the most efficient distribution of the area to be treated for civil protection purposes (TOM BAU) as shown in **Figure 37**

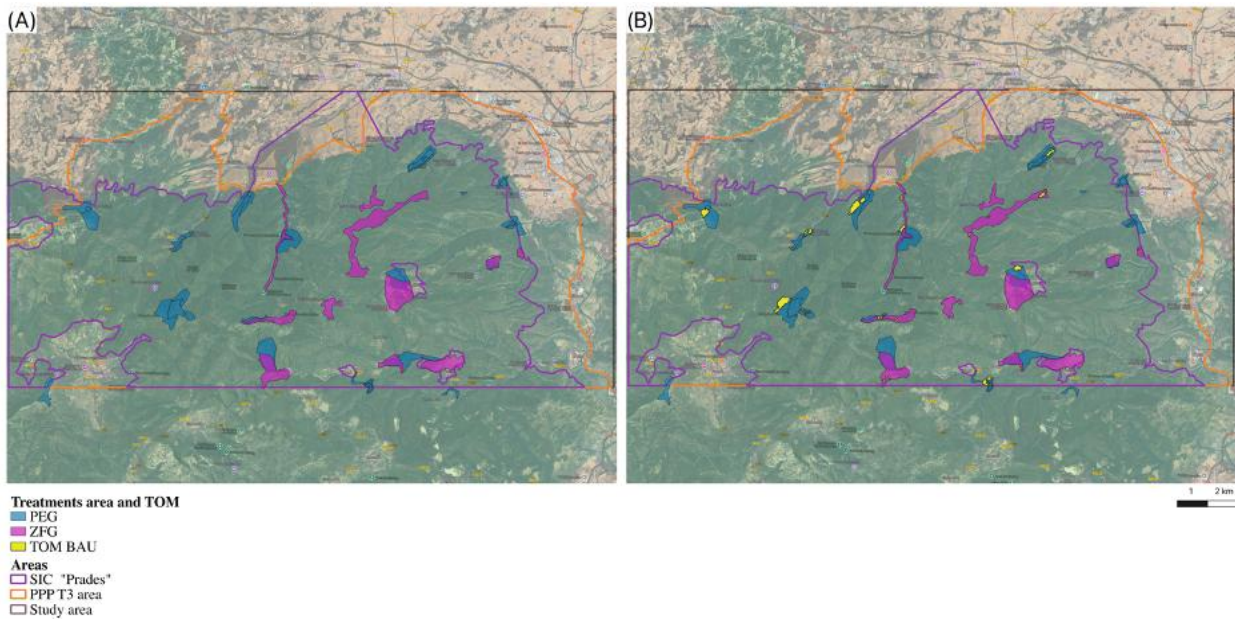


Figure 37 - (A) Intervention zones identified by the current planning (PPP T3): PEG and ZFG; (B) Optimisation of the area to be treated within the zones identified by the current planning to achieve the civil protection objective.

3.3.5. Analysis of historical fires

In the historical period 1986-2012, 8 fires occurred in the area, covering a total area of 2396 ha (**Figure38**). The number of events occurring each year is less than 1 (0.3), while the average annual area covered is 88.7 ha/year. In the study area, the number of medium sized fires (e.g. 50 ha) was very high (**Figure 39**) and, periodically, there were years predisposing to fires where the annual area burned was particularly high (>100 ha). The largest fire occurred in 1986 (1960 ha) (**Figure 40**).

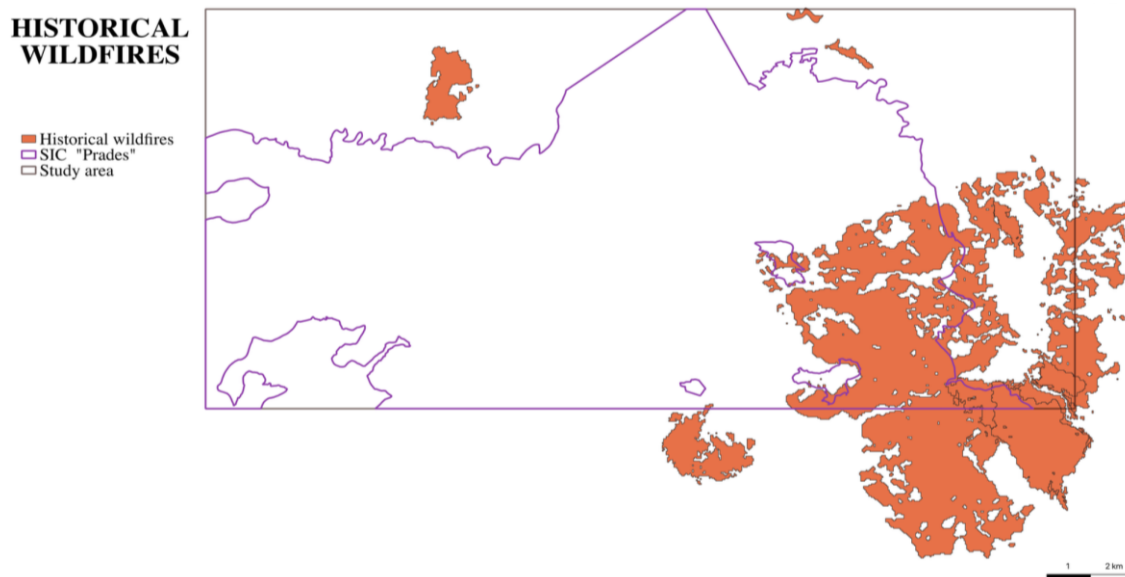


Figure38 - Historical fires occurred in the study area in the period 2007-2023.

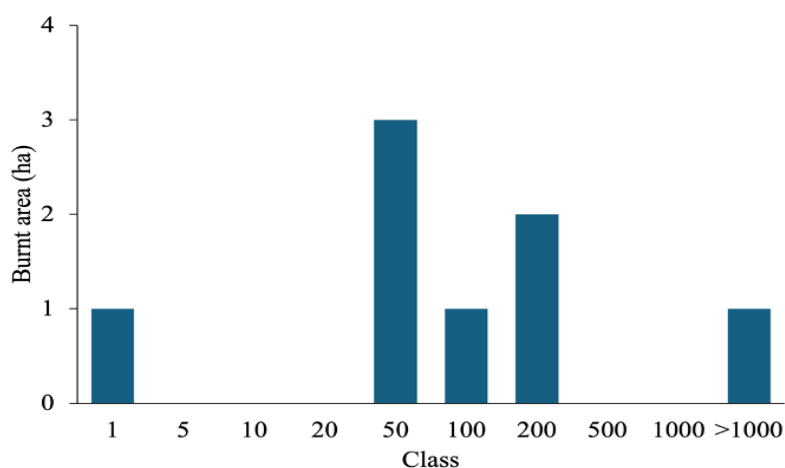


Figure 39 - Size class distribution of the area covered by fires in the study area.

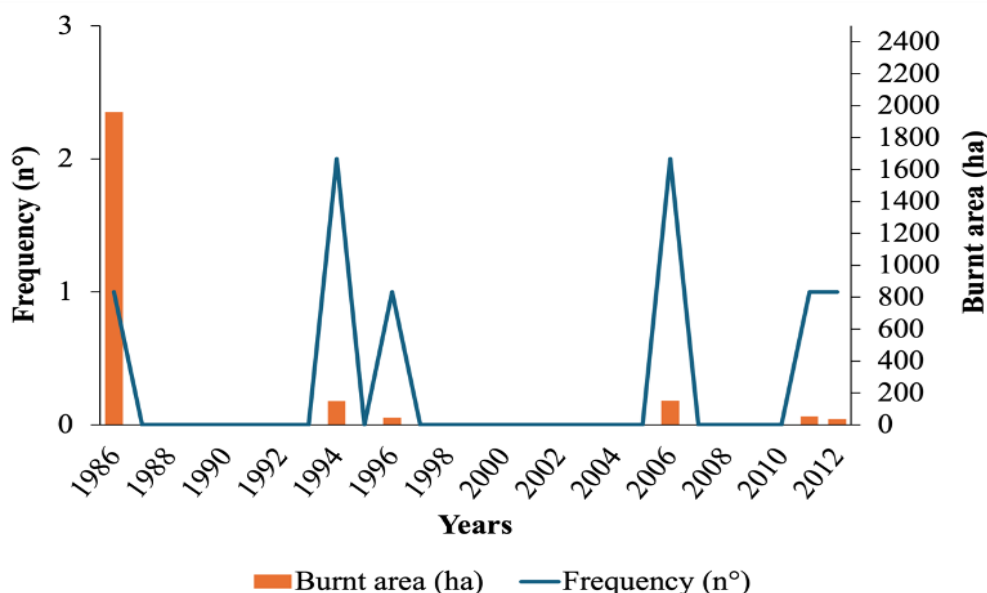


Figure 40 - Fire frequency distribution and annual burnt area in the study area for the period 1986-2012.

18.3 % (2161 ha) of the area historically affected by fire occurred in the RN2000 Site area included in the study area. The fires that occurred were of medium to large size and mainly concentrated in the summer period (July) (**Table 23**). The target habitat (9350*) present within the SCI was affected by the large fire in 1986 covering an area of 29 ha.

Table 23 - Fires occurring in the 'Prades' SCI, within the study area, in the period 1986-2012

Year	Burnt area (ha)	Dates
1986	1960	06/07/86
1994	148	17/07/94
1994	1	07/07/94
2011	52	19/07/11

3.3.6. Pre- and Post-implementation Burn Probability (BAU) and application of the TOM for their relocation

Figure 41 the distribution of the areas for fire prevention identified by the current planning in the T3 PPP of Muntanyes de Prades is shown (**Figure 41 A** - Treatments BAU - polygons in purple) and the optimised spatialisation of this area through the use of the TOM (**Figure 41 B** - TOM BAU - polygons in yellow). **Figure 41 C** shows the distribution of the treatment opportunities where fire prevention interventions can be placed for the different objectives (Treatment opportunities - polygons in grey) and the output of the application of the TOM model, which made it possible to spatialise the fire prevention interventions with a civil protection objective within the treatment opportunities (**Figure 41 C** - TOM BAU optimised - polygons in blue). **Figure 41 D** compares the optimised spatialisation of interventions under current planning (in yellow) and the optimised spatialisation of interventions within treatment opportunities (in blue).

Figure 42 it can be observed how the optimised spatialisation of interventions (TOM BAU optimised) intercepts the preferential propagation trajectories that originate from a selection of trigger points extracted from the initial 5000 points (using hexagonal cells as extraction units) and that give rise to large fires (see section 3.1.5).

Figure 43 shows the fire probability analysis in the scenario in the absence of preventive interventions (PRE scenario), in the presence of the interventions planned by the T3 PPP of Muntanyes de Prades (BAU scenario) and following the optimised spatialisation of preventive infrastructures using the TOM (optimised BAU scenario).

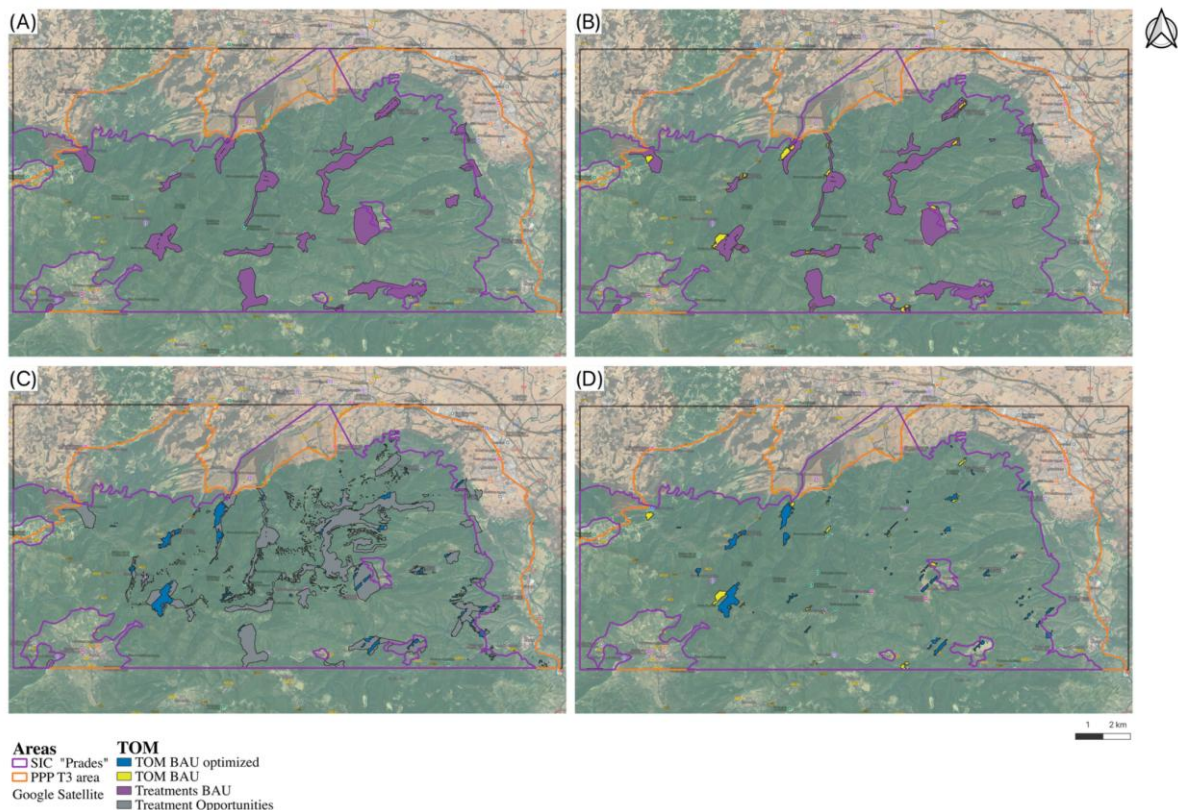


Figure 41 - (A) Intervention zones identified by the current planning (PPP T3); (B) optimisation of the area to be treated within the zones identified by the current planning to achieve the civil protection objective; (C) optimised spatialisation of fire prevention interventions with civil protection objective within the Treatment opportunities; (D) comparison between the spatialisation of interventions within the zones identified by the current planning and within the Treatment opportunities.

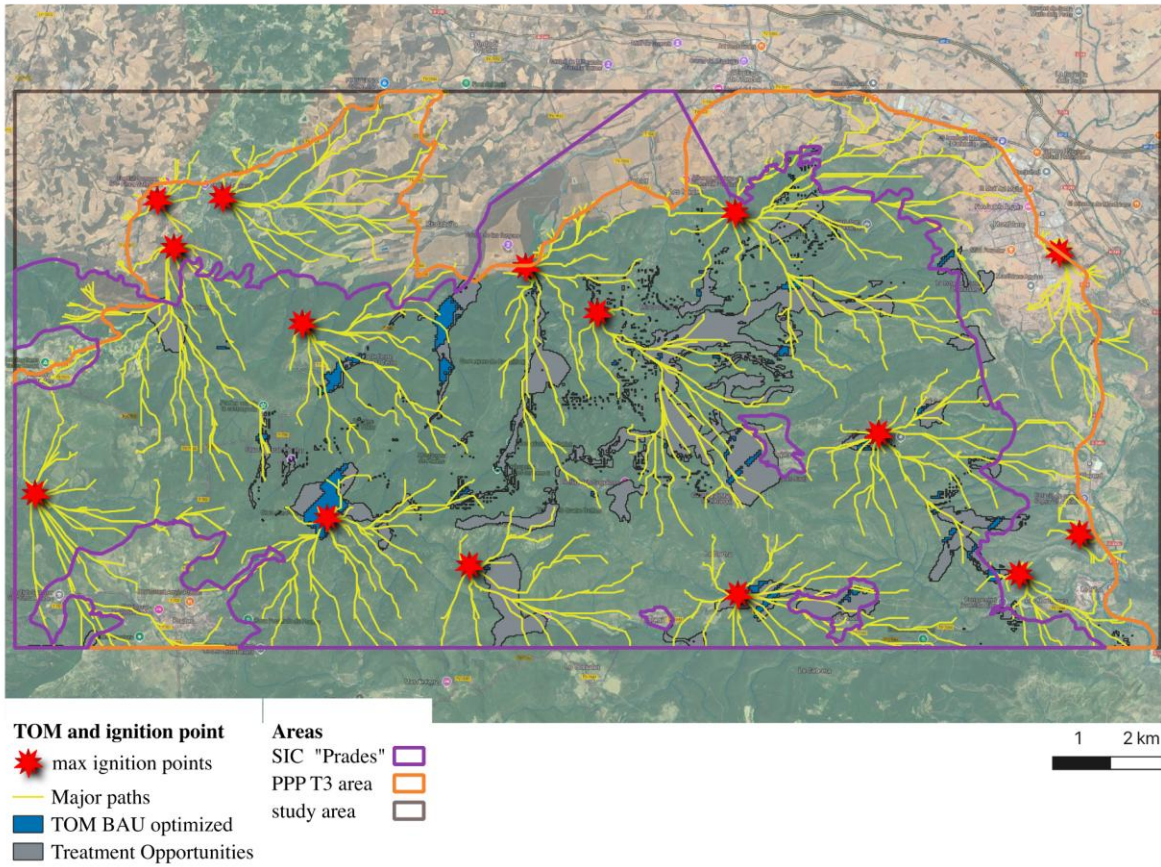


Figure 42 - Optimized spatialization of fire prevention interventions with civil protection objectives.

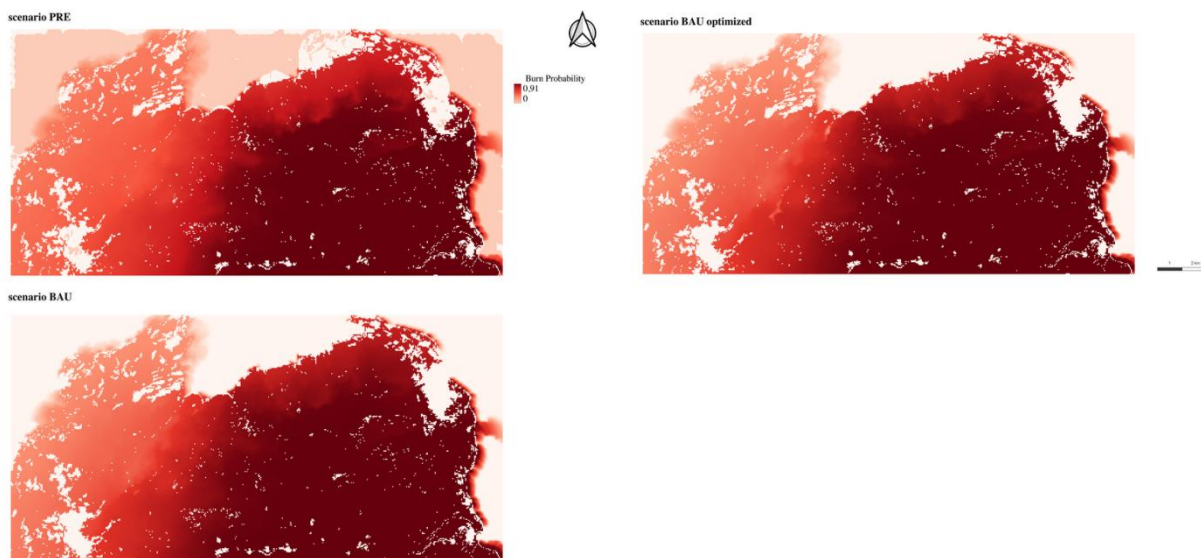


Figure 43 - Burn Probability in the scenario in the absence of fire prevention interventions (PRE), after the implementation of the planned interventions, post-optimization through the use of the TOM (BAU) and after the spatial optimization of the interventions with civil protection objective (BAU optimized).

3.3.7. Proposal for spatialization of interventions for the protection of biodiversity and calculation of post-intervention Burn Probability

Figure 44 shows the distribution of treatment opportunities, where fire prevention interventions can be placed for the different objectives (Treatment opportunities – polygons in grey), and the application of the TOM model, which has made it possible to spatialize fire prevention interventions with the objective of biodiversity conservation (TOM BIO – polygons in green). It can be observed that the optimized spatialization of the interventions (TOM BIO) intercepts the preferential propagation trajectories that originate from the ignition point (max ignition point BIO). This ignition point has been selected among the ignition points that originate large fires within the landscape, and responsible for the large fire that would intercept or affect the CAs and IBs (see **paragraph 3.1.6**)

Figure 45 shows the analysis of the probability of fires running in the scenario in the absence of preventive interventions (PRE scenario) and following the optimized spatialization of preventive infrastructures with the objective of biodiversity conservation using the TOM (BIO scenario).

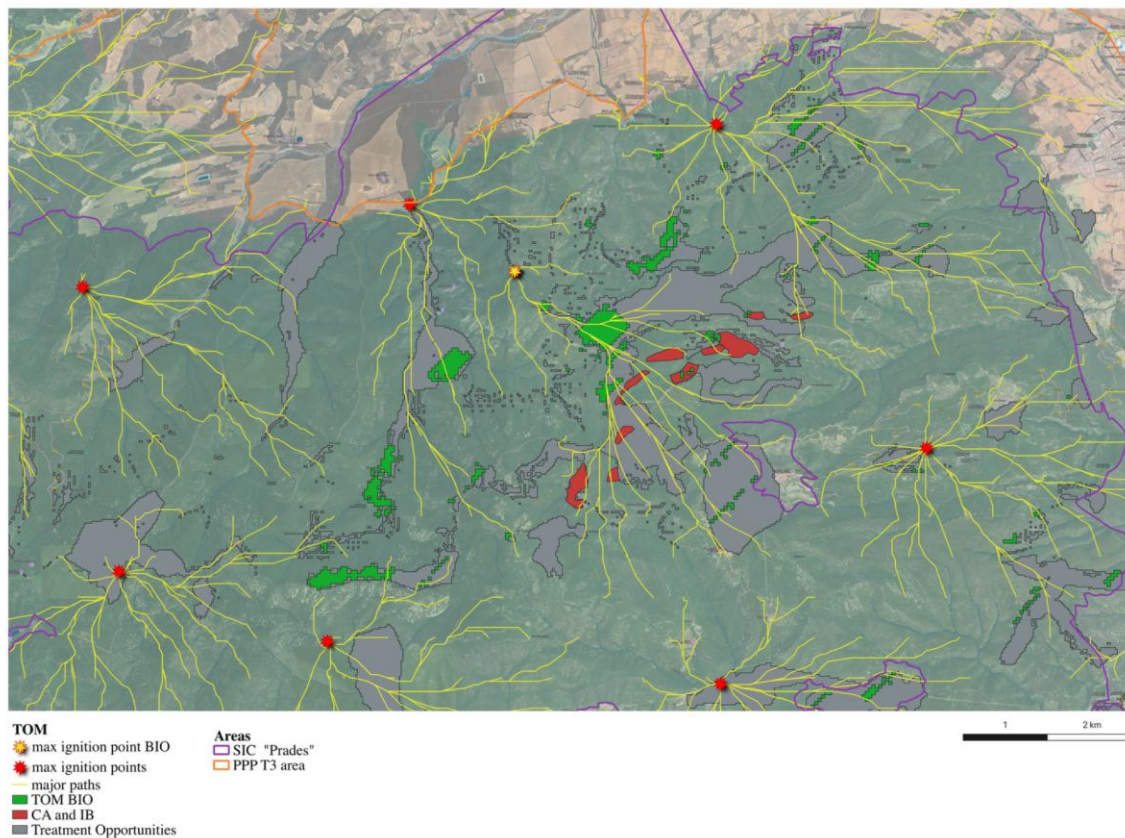


Figure 44 - Optimized spatialization of fire prevention interventions with the objective of biodiversity conservation.

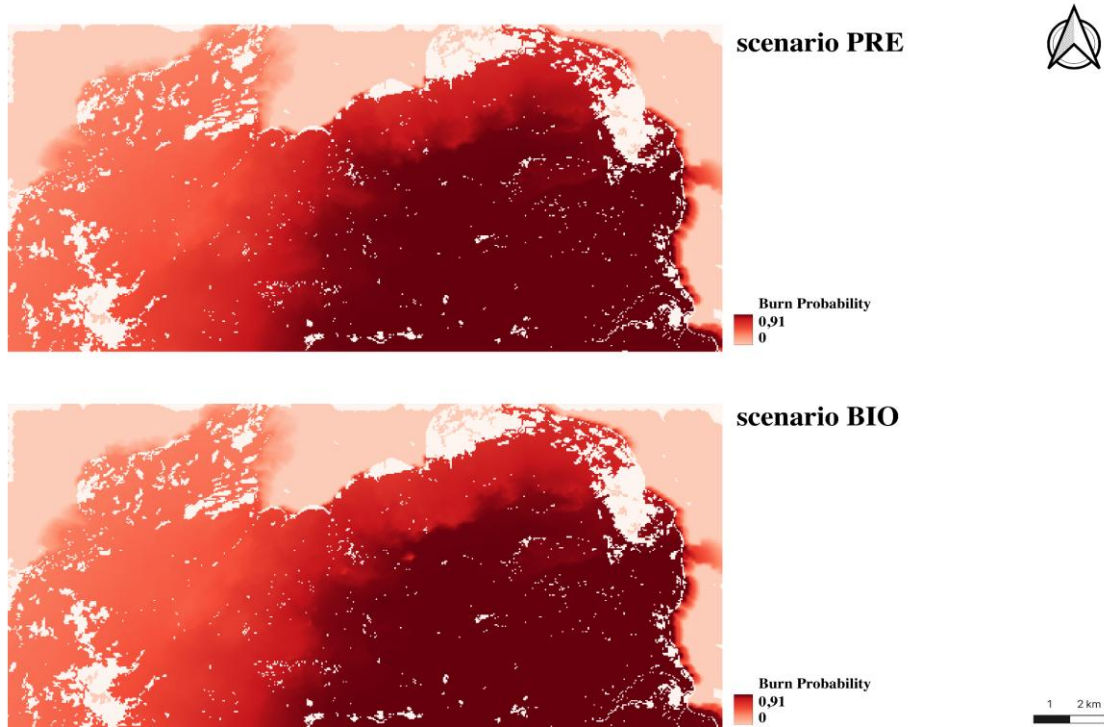


Figure 45 - Burn Probability in the scenario in the absence of fire prevention interventions (PRE) and after the spatial optimization of interventions with the objective of biodiversity conservation (BIO).

3.3.8. Proposal for the spatialization of interventions to obtain the trade-off of the areas to be treated for the achievement of the objectives of civil protection and biodiversity conservation

Figure 46 shows the distribution of treatment opportunities where fire prevention interventions can be placed for the different objectives (**Figure 46A** – Treatment opportunities – polygons in grey). The application of the TOM model has made it possible to spatialize fire prevention interventions with the objective of civil protection (**Figure 46B** – TOM BAU optimized – polygons in blue) and with the objective of biodiversity conservation (**Figure 46C** – TOM BIO – polygons in green). **Figure 46D** shows the trade-off in the distribution of the surfaces of fire prevention interventions to achieve both the objectives of civil protection and biodiversity conservation (TOM TRADE-OFF – polygons in pink).

Figure 47 shows the analysis of the probability of fires running in the scenario in the absence of preventive interventions (PRE scenario) and following the optimized spatialization of preventive infrastructures using the TOM to achieve both objectives (TRADE-OFF scenario).

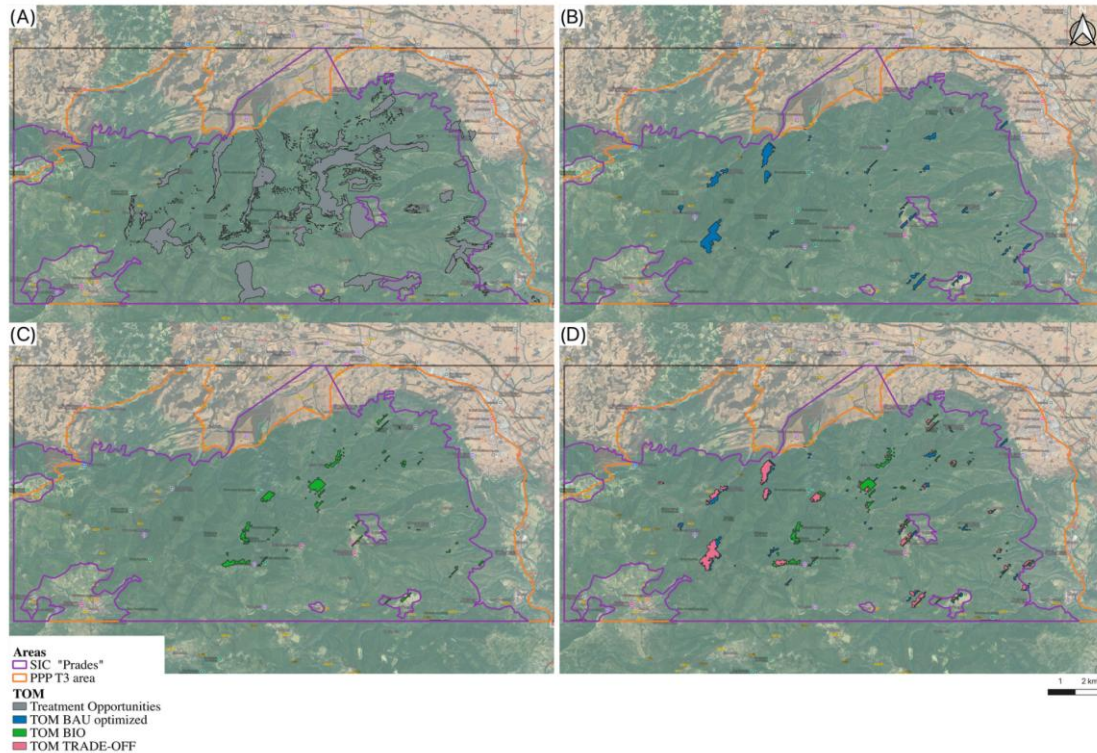


Figure 46 - (A) Treatment opportunities where fire prevention interventions can be placed for the different objectives; (B) optimized spatialization of fire prevention interventions with civil protection objectives; (C) spatialization optimizes fire prevention interventions with the aim of preserving biodiversity; (D) trade-off of the areas of intervention to achieve both the objectives of civil protection and biodiversity conservation.

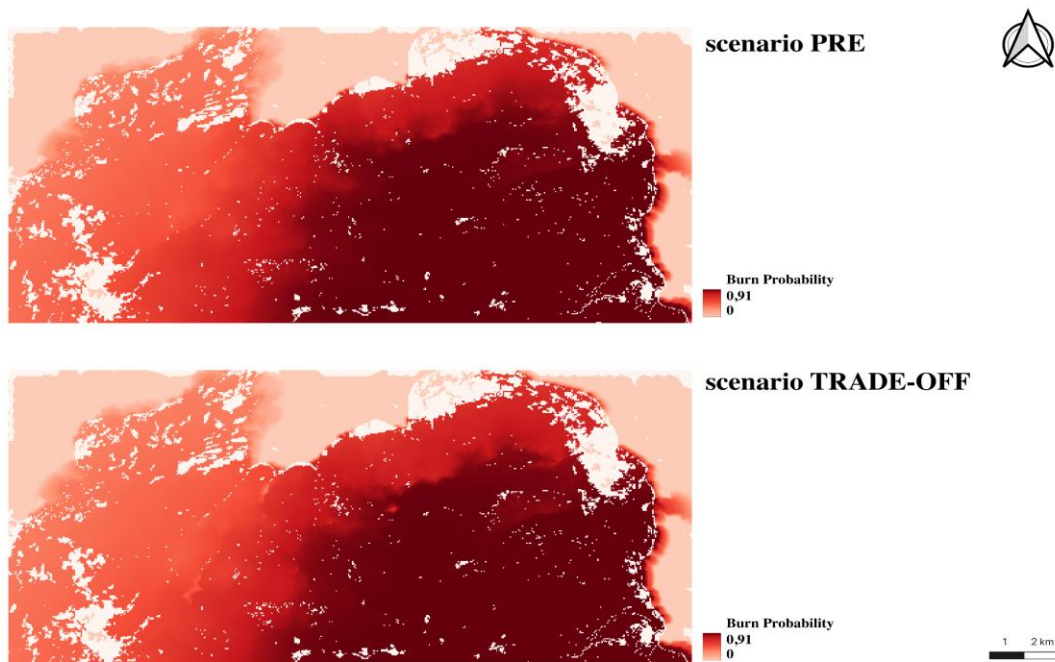


Figure 47 - Burn Probability in the scenario in the absence of fire prevention interventions (PRE) and the implementation of the interventions on the surfaces identified by the Treatment Optimization Model as the surfaces that allow to achieve both objectives of civil protection of biodiversity conservation (TRADE-OFF).

3.3.9. Evaluation of the variation in the probability of fires occurring and the distribution of potential fires in different spatialisation scenarios of fire prevention interventions

The **Figure 48** shows the map of fire risk in the absence of fire prevention interventions (risk PRE). This map was created using a combination matrix of the hazard classes in the absence of preventive infrastructure (Hazard PRE, **section 3.1.1**) and the potential impact (Potential impact, **section 3.1.2**) (**Figure 49**).

Table 24, for the landscape areas falling in the Very High risk class, the difference (delta) between the average probability of travel in the scenario without fire prevention interventions (PRE) and in the scenarios of optimised fire prevention interventions with a civil protection objective (BAU opt), of biodiversity conservation (BIO) and of trade-off of areas between the two objectives (TRADE-OFF) was calculated. The ratio between the delta between the PRE scenario and the optimised BAU scenario (delta PRE-BAUopt) and the delta between the PRE scenario and the BIO scenario (delta PRE-BIO) and the TRADE-OFF scenario (delta PRE-TRADE-OFF) shows that the BIO scenario leads to a 19.0 % greater reduction in Burn Probability compared to the optimised BAU scenario; the reduction in the probability of a fire occurring is 56.0 % greater in the TRADE-OFF scenario compared to the optimised BAU scenario. These results highlight the greater effectiveness in reducing burn probability through the trade-off of areas dedicated to fire prevention infrastructure to achieve both objectives.

Table 25, for each exposure, the difference (delta) between the average travel probability in the scenario with no fire prevention interventions (PRE) and in the scenarios of optimised fire prevention interventions with civil protection objective (BAU opt), biodiversity conservation (BIO) and area trade-off between the two objectives (TRADE-OFF) was calculated. The ratio between the delta between the PRE scenario and the optimised BAU scenario (delta PRE-BAUopt) and the delta between the PRE scenario and the BIO scenario (delta PRE-BIO) and the TRADE-OFF scenario (delta PRE-TRADE-OFF) shows how the optimised BAU scenario leads to greater Burn Probability reduction than the BIO scenario for all exposures (Biodiversity, reduction of 90.5 %; Habitat, 21.8 % reduction; Forest Ecosystem Services, 24.4 % reduction; Soil erosion, 38.4 % reduction; Urban-wilderness Interface, 7.7 % reduction). The greatest reduction in the probability of a fire occurring was observed in the TRADE-OFF scenario (average BP reduction greater than 63.8 ± 16.5 % compared to the optimised BAU scenario) for all exposures. These results underline the effectiveness in reducing the probability of fire passage of the spatialisation of interventions with a civil protection objective, but above all a greater effectiveness in reducing the probability of fire passage through the trade-off of the areas dedicated to the construction of fire prevention infrastructures to achieve both objectives (**Figure 50**).

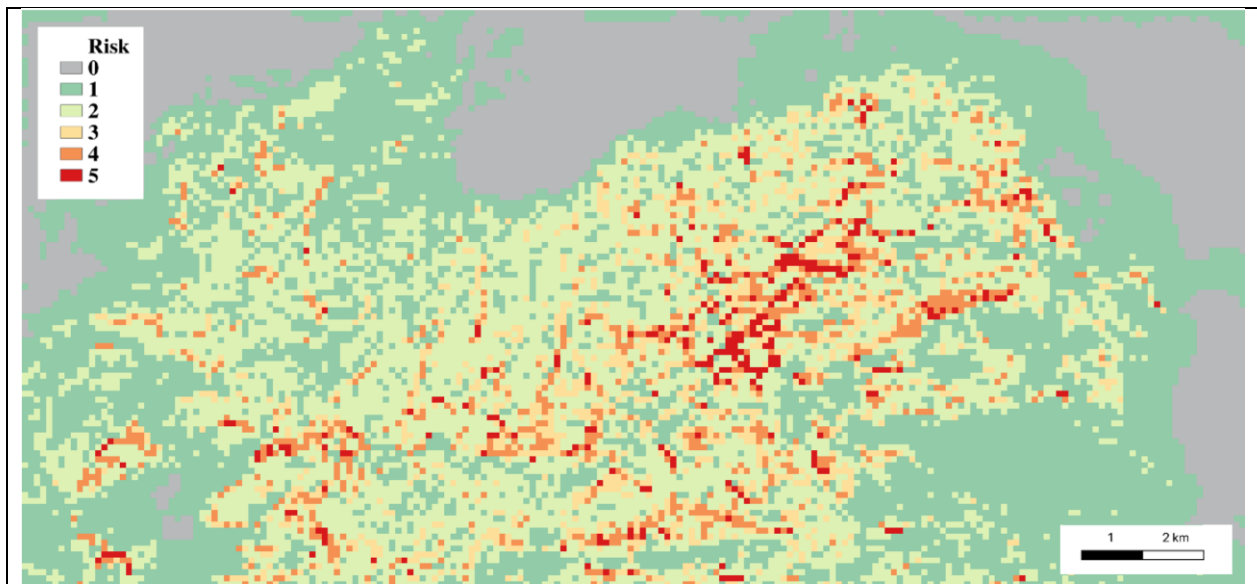
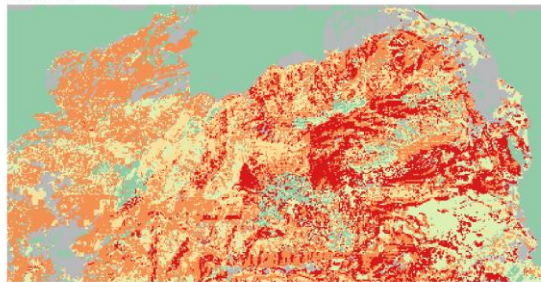


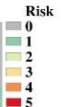
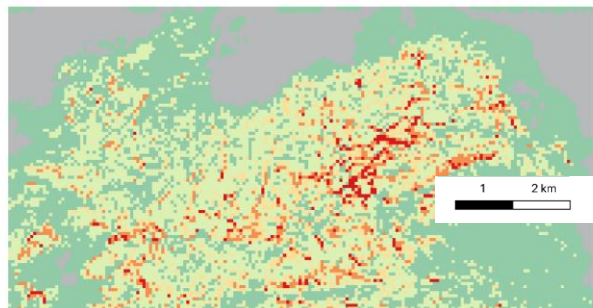
Figure 48 - Fire risk in the absence of fire prevention measures (risk PRE) divided into classes.



Hazard PRE



Risk PRE



Potential impact

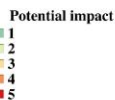
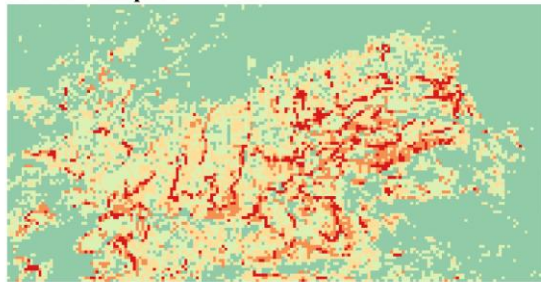


Figure 49 - Hazard in the absence of preventive infrastructure (Hazard PRE), Potential impact (Potential impact) and Fire risk in the absence of fire prevention measures (Risk PRE) divided into classes.

Table24 - Delta: difference between the average Burn Probability in the scenario without fire prevention interventions (PRE) and in the optimised BAU scenario (BAUopt), BIO and TRADE-OFF for the landscape areas in fire risk class Very High; Delta ratios: ratio

between the delta of Burn Probability PRE-BAU optimised (BAUopt) and the deltas of Burn Probability PRE-BIO and PRE-TRADE-OFF for the landscape areas in fire risk class Very High..

Delta		
PRE-BAUopt	PRE-BIO	PRE-TRADEOFF
0.004529	0.005529067	0.010391
Rapporti dei delta		
deltaPRE-BAUopt/ deltaPRE-BIO	deltaPRE-BAUopt/ deltaPRE-TRADEOFF	
0.81905	0.435821	

Table 25 - Delta: Difference between the average Burn Probability in the scenario without fire prevention interventions (PRE) and in the optimised BAU scenario (BAUopt), BIO and TRADE-OFF for each exposure; Delta ratios: ratio between the delta of Burn Probability PRE-BAU optimised (BAUopt) and the deltas of Burn Probability PRE-BIO and PRE-TRADE-OFF for each exposure.

	PRE-BAUopt	PRE-BIO	PRE-TRADE-OFF	deltaPREBAUopt/ deltaPREBIO	deltaPREBAUopt/ deltaPRETRADE-OFF
Biodiversity	0.000734	0.007728	0.009871	0.094913	0.074306
Habitat	0.005799	0.007421	0.013237	0.781484	0.438107
Forest Ecosystem Services	0.006032	0.007981	0.014064	0.755779	0.428897
Soil Erosion	0.005958	0.009673	0.015639	0.615905	0.380972
Urban-wilderness Interface	0.006322	0.006849	0.013002	0.923038	0.486214

Figure 51 shows the distribution of simulated potential fires in the different surface area classes for each scenario.

Differences were found above all in size classes 13 to 18, i.e. for fires from 1000 to 15000 ha, where there was an increase in the frequency of potential fires in classes 15 and 16 respectively: by 1.3 ± 1.0 % in the BAU scenario, 5.2 ± 4.1 % in the optimised BAU scenario (BAU opt), 10.9 ± 8.0 % in the BIO scenario and 18.1 ± 6.3 % in the TRADE-OFF scenario. Only in the optimised BAU, BIO and TRADE-OFF scenarios was there an increase in the frequency of potential fires in class 13 (range: 1000-3000 ha) averaging 5.3 ± 2.3 %; there was a 3.6 % decrease in the number of simulated fires in class 14 (range: 3000-5000 ha) in the BIO scenario, and a 3.6 % increase in the optimised BAU scenario.

On the other hand, in size classes 17 and 18 (range: 10000-15000 ha) there was a decrease in the frequency of potential fires by, respectively: 0.8 ± 0.3 % in the BAU scenario, 4.3 ± 1.5 % in the optimised BAU scenario (BAU opt), 6.1 ± 7.2 % in the BIO scenario and 11.7 ± 10.3 % in the TRADE-OFF scenario. These results underline how the greatest effectiveness in reducing the size of potential fires was obtained with the trade-off of the areas dedicated to the construction of fire prevention infrastructures to achieve both objectives (TRADE-OFF scenario), followed by the optimised spatialisation of interventions with the objective of biodiversity conservation (BIO scenario) (**Table 26** and **Figure 51**).

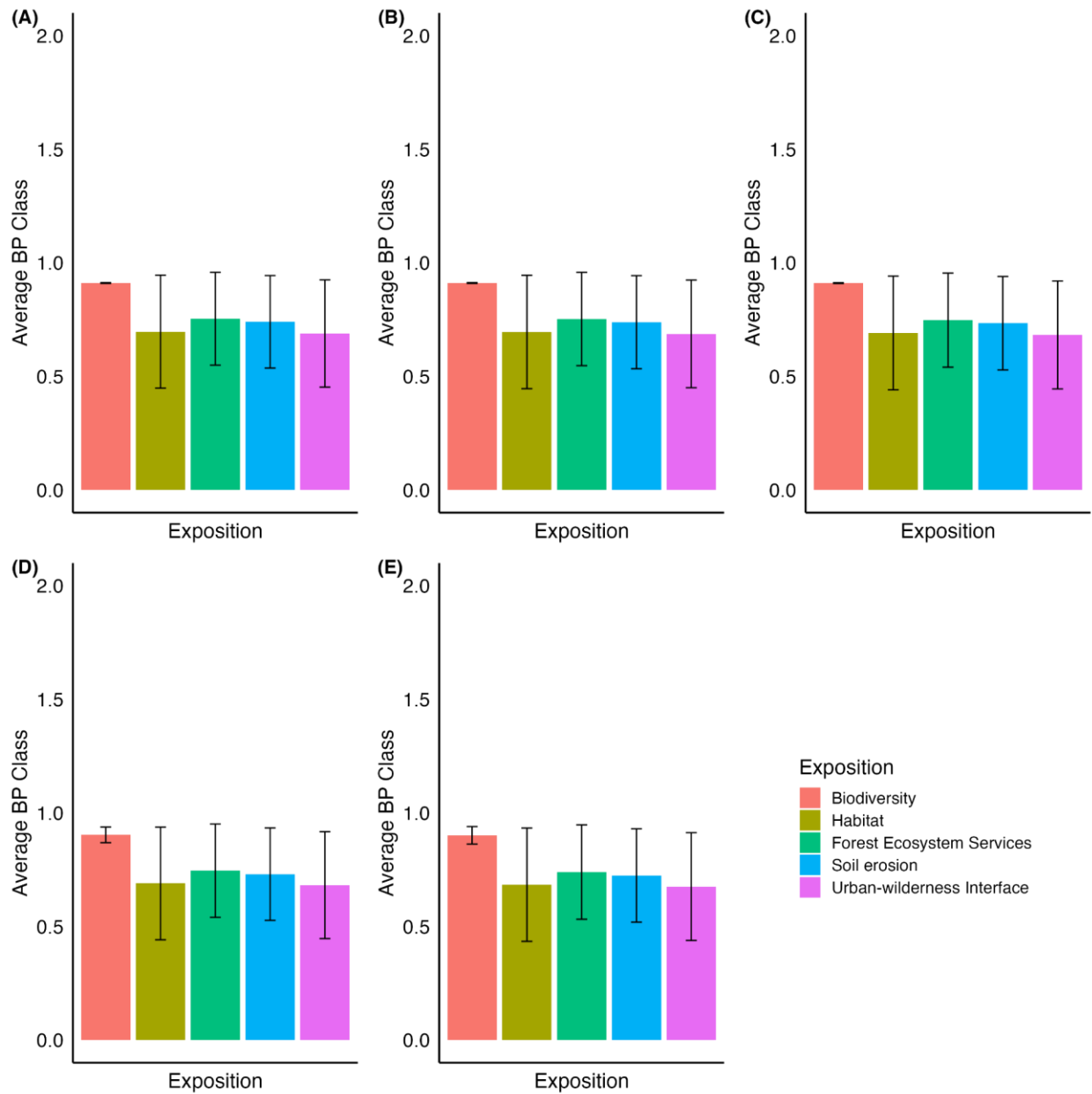


Figure 50 - Mean Burn Probability ($\pm SD$) in the exposures in the different fire prevention spatialisation scenarios: (A) PRE, (B) BAU, (C) optimised BAU, (D) BIO, (E) TRADE-OFF).

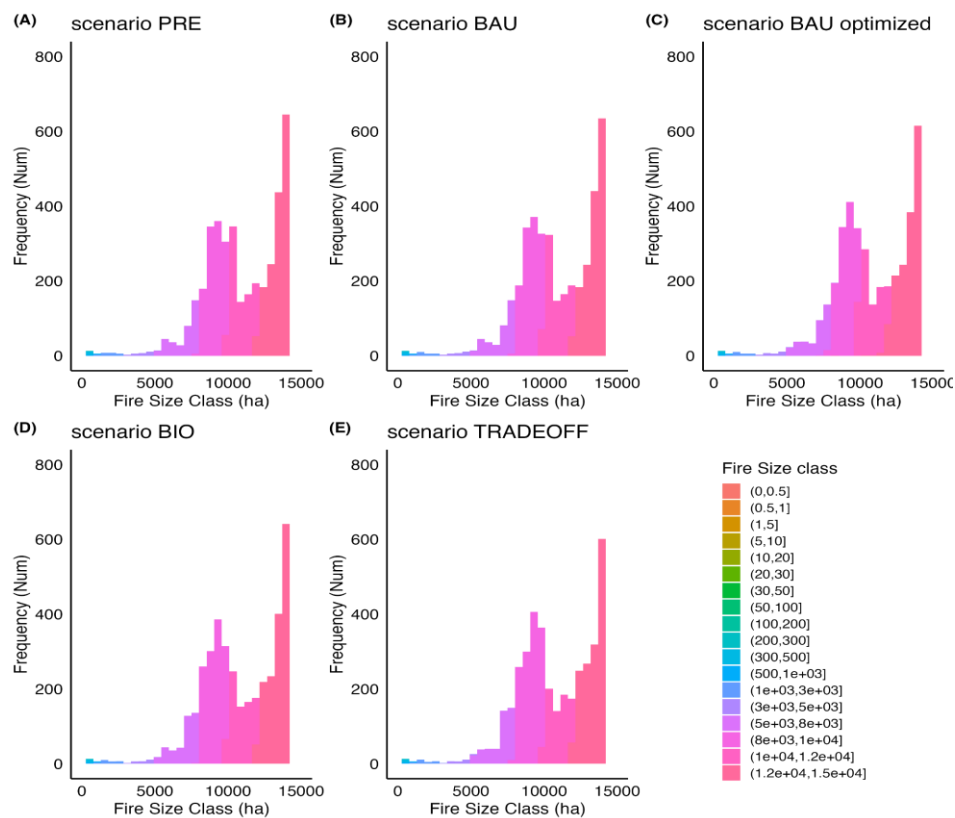


Figure 51 - Size class distribution of potential fires in the different fire prevention spatialisation scenarios: (A) PRE, (B) BAU, (C) BAU optimised, (D) BIO, (E) TRADE-OFF.

Table 26 - Relationship between the relative frequencies of potential fires in the different scenarios of spatialisation of fire prevention interventions and the relative frequencies of potential fires in the scenario without fire prevention interventions (PRE) for each size class.

N Fire Size	Fire Size Class	BAU/PRE	BAUopt/PRE	BIO/PRE	TRADEOFF/
1	[0,0.5)	0.991266	0.994178	0.994178	0.994178
2	[0.5,1)	0.857143	0.857143	0.857143	0.857143
3	[1,5)	1	1	1	1
4	[5,10)	1	1	1	1
5	[10,20)	1	1	1	1
6	[20,30)	1	1	1	1
7	[30,50)	1	1	1	1
8	[50,100)	1	1	1	1
9	[100,200)	1	1	1	1
10	[200,300)	1	1	1	1
11	[300,500)	1	1	1	1
12	[500,1000)	1	1	1	1
13	[1000,3000)	1	1.04	1.04	1.08
14	[3000,5000)	1	1.035714	0.964286	1
15	[5000,8000)	1.005797	1.023188	1.165217	1.226087
16	[8000,10000)	1.02109	1.080844	1.052724	1.137083
17	[10000,12000)	0.989424	0.945946	0.887192	0.809636
18	[12000,15000)	0.993602	0.96737	0.989763	0.955854

4. Conclusions

4.1. Preventive silviculture on a stand scale

In Deliverable 3.2, the **stand scale** addressed **the integration between** silvicultural **prescriptions** for the conservation of habitats 9530* and 9260 and prescriptions that aim to reduce the flammability of forest stands **within preventive infrastructures** such as fuelbreaks to support active firefighting and stand self-resistance zones. The **approach proposed in Deliverable 3.2** offers a replicable method for assessing the degree of conflict between silvicultural prescriptions.

As regards fuelbreaks in the vicinity of the ecological network (see diagrams: **Figure 52** **Figure 53** **Figure 54** **Figure 55**, and **Figure 56**).

- **Habitat 9260:** (i) for Core Areas (CA): when active firefighting support roads are present in the proximity of the CA, it is always necessary to implement interventions outside the CA, for a strip at least 50-70 m wide (depending on slope and morphology) and at least 1000 m long along the roadway in the proximity of the CA itself. Perimeter interventions inside the CA, if functional to the effectiveness of the fuelbreaks, are to be implemented for a strip of depth of 20-30 m. (ii) For the Islands of Biodiversity (IBs): when active firefighting support roads are present in the vicinity of larger and more fire-risk prone IBs (regardless of whether they are of the "conservative" or "improved" type), it is always necessary to implement interventions outside the IBs, in the direction of the most probable fire, for a minimum band of 70 m in width (depending on the slope and morphology) and a minimum band of 500 m in length along the roads placed in the vicinity of the individual IBs. Perimeter interventions inside the IBs, if functional to the effectiveness of the fuelbreaks, are to be implemented for a strip 20-30 m deep.
- **Habitat 9530*:** (i) for Core Areas (CA): when active firefighting support roads are present in the proximity of the CA, it is always necessary to implement interventions outside the CA, for a strip at least 80-100 m wide (depending on slope and morphology) and at least 1000 m long along the roadway in the proximity of the CA itself. Perimeter interventions inside the CA, if functional to the effectiveness of the fuelbreaks, are to be implemented for a depth strip of 30-50 m. (ii) For the Islands of Biodiversity (IBs): when active firefighting support roads are present in the proximity of IBs with a higher fire hazard and of greater dimensions (regardless of whether they are of the "conservative" or "improved" type), it is always necessary to implement interventions outside the IBs, in the direction of the most probable fire, for a minimum band of 80-100 m in width (depending on the slope and morphology) and of a minimum length of 500 m along the roads placed in the proximity of the individual IBs. Perimeter interventions inside the IBs, if they are functional to the effectiveness of the fuelbreaks, are to be implemented for a depth band of 30-50 m.

Regarding the self-resistance infrastructure of stands, it is useful to bear in mind when assessing the coherence between silvicultural indications for Natura 2000 habitats and prevention measures:

- **Civil protection priorities:** When it is necessary to intervene within a protected area with a fuelbreak, technical rules to ensure the safety of firefighting operators take precedence over other principles. In these cases, it is necessary to derogate from the specific conservation measures for the portion of the fuelbreak with basal area harvesting and cover reduction that are not always consistent with conservation measures.
- **Finding the trade-off:** When marking trees to be cut, is necessary to assess the ecological value of the individual tree and its flammability relationship with neighbouring trees, especially in the presence of conifers that support crown fire. In many situations, it is possible to leave old trees full of dendromicrohabitats with flammability characteristics (e.g. resin flows, rosin) and therefore work with the silviculture of trees or groups around the candidate trees, to avoid the transmission of a crown fire or a lethal thermal dose to the candidate trees.

- **Deadwood:** To protect individual trees or groups of trees in a habitat, it is also necessary to intervene on the flammable surface biomass, and therefore on the deadwood. Deadwood is one of the most flammable components, and accumulations can generate high intensities and severity levels (e.g., Val Susa fire in 2017). However, the flammability of deadwood is inversely proportional to its size and only if all size classes of dead wood are present does the fuel complex become highly flammable. Often, to achieve the objectives of biodiversity conservation, it is necessary to guarantee the presence of deadwood of larger dimensions, while the size classes below 7,5 cm are of less interest, but it is precisely these that determine the propagation of the flame front and the increase in intensity. Reducing the most flammable fraction of the deadwood by releasing the larger ones is a preventive activity that can be carried out around individual or groups of habitat trees. Selective regulation of deadwood can also be obtained by prescribed fire treatments that reduce the smaller fraction without involving the larger diameters in the combustion because they are more humid in the presence of close rainfall. The spatial distribution of deadwood can also contribute to increasing the resistance of a stand. Even though it guarantees a good level of deadwood in the forest, this should be kept away from groups of trees that are habitats, avoiding accumulations, especially in the impluvium areas where the intensity of the flame front can increase, and generally guaranteeing a discontinuity created by a checkerboard pattern of portions of forest where deadwood is present and portions where it is removed.

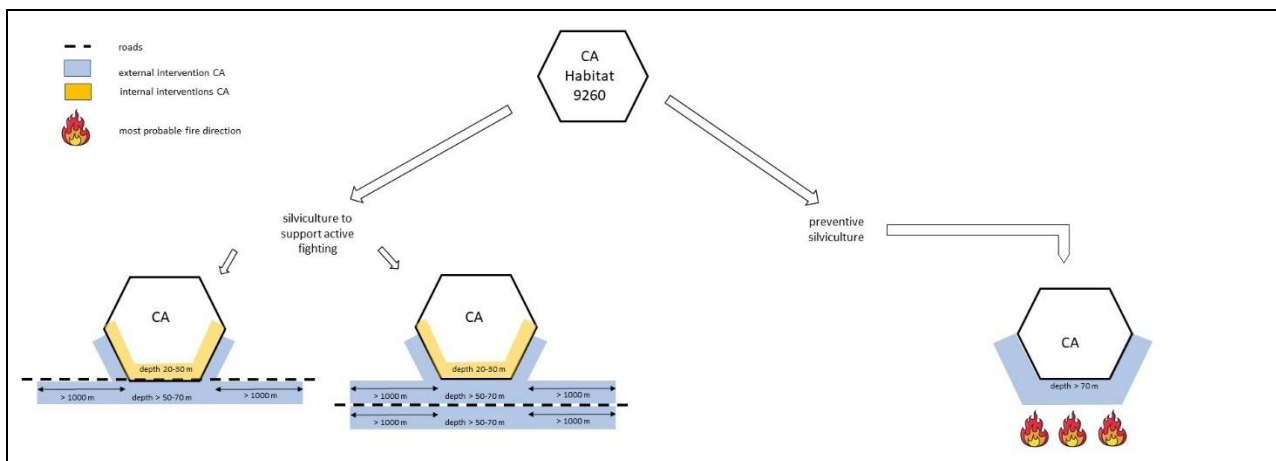


Figure 52 - CA intervention scheme for Habitat 9260

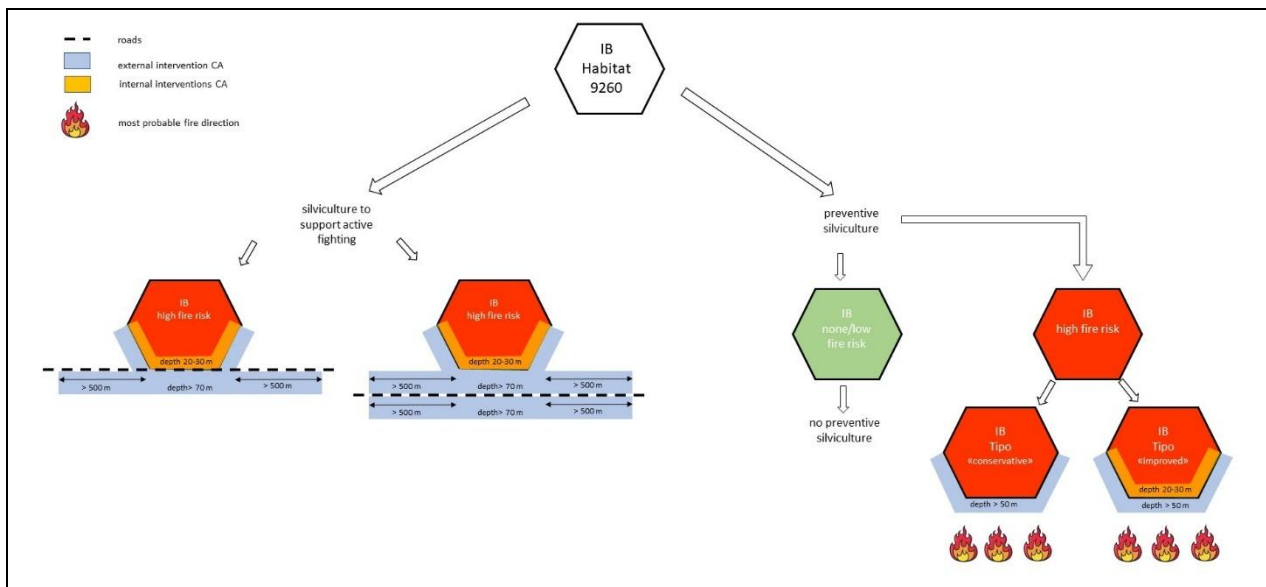


Figure 53 - IB intervention scheme for Habitat 9260

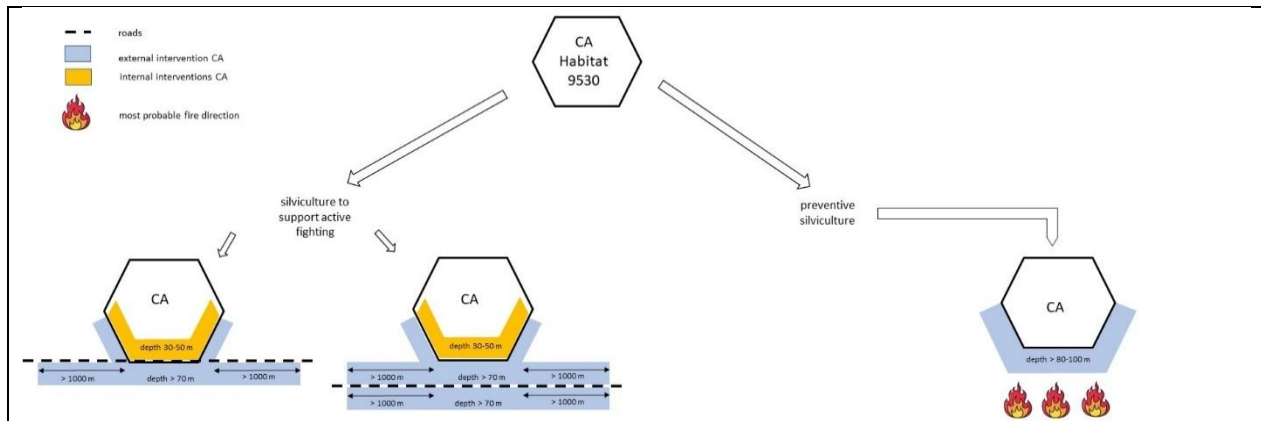


Figure 54 - CA intervention scheme for Habitat 9530

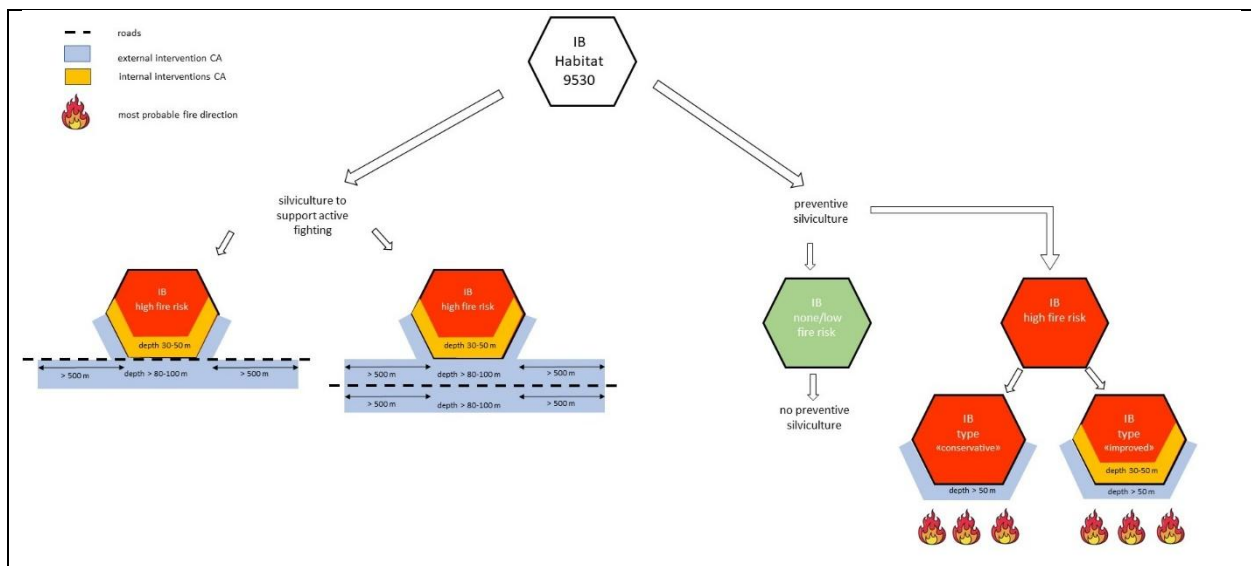


Figure 55 - IB intervention scheme for Habitat 9530

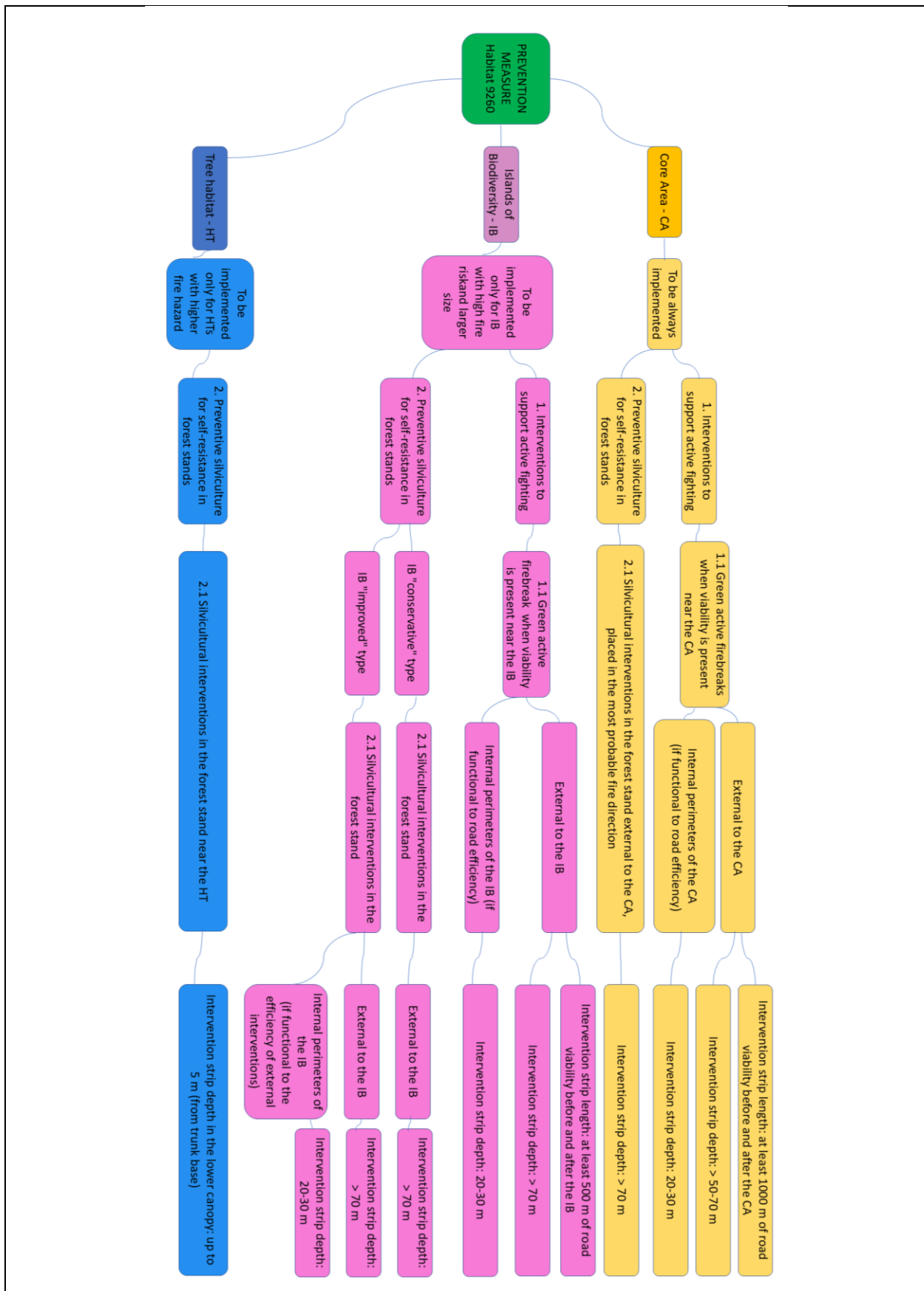


Figure 56 - Mental map of prevention interventions Habitat 9260

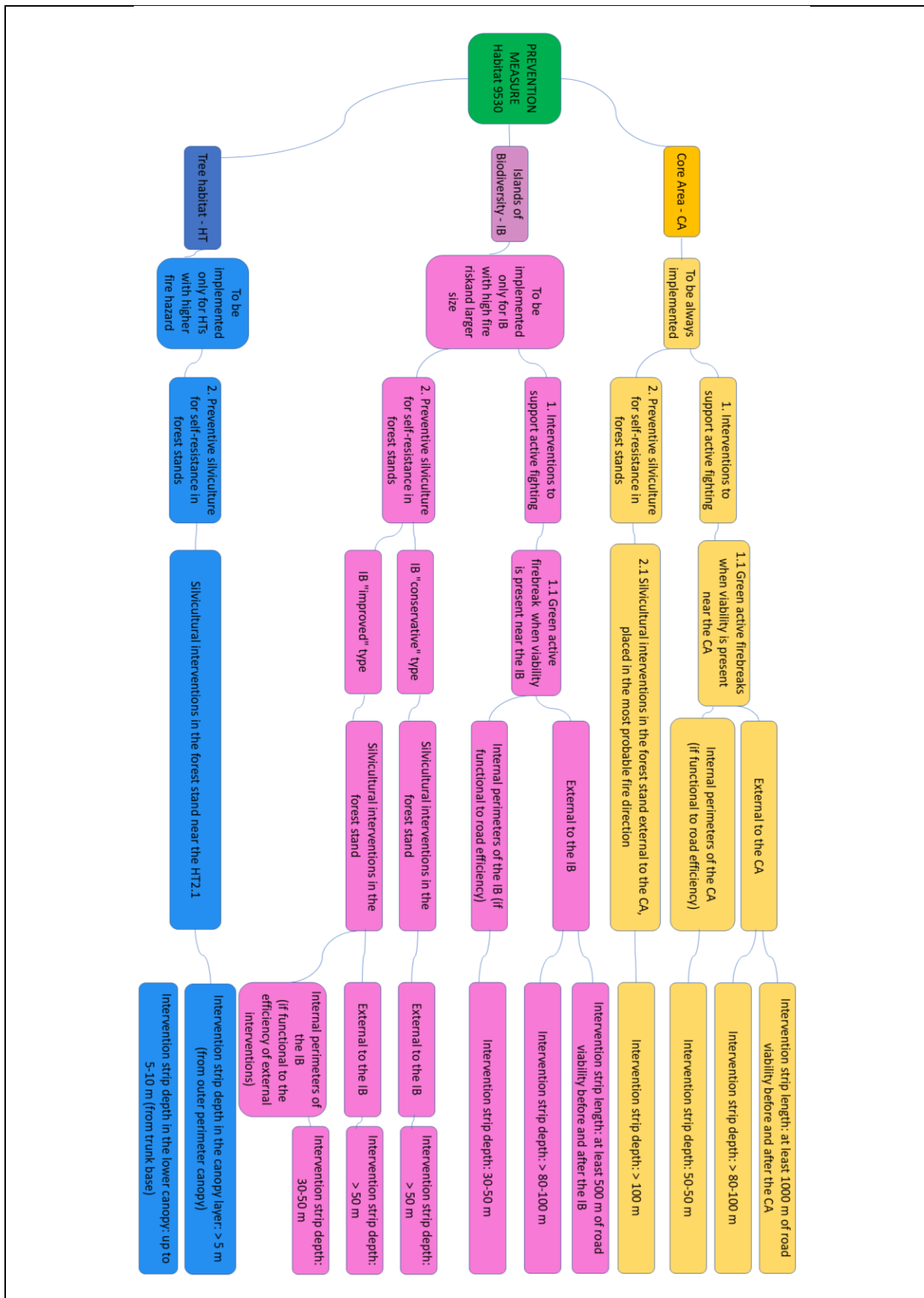


Figure 57 - Mental map of prevention interventions Habitat 9530

4.2. Integrated planning on a territorial scale

The strategic planning of preventive infrastructures aims at finding a **compromise between the protection of different objectives** (biodiversity, protection of the urban-rural interface, soil protection) while trying to optimise investments for the mitigation of fire impacts at a territorial scale. The **method proposed in Deliverable 3.2** offers a replicable quantitative analysis procedure. The method, however, can be improved with further analyses combining different scenarios:

- **Alternative resource scenarios for prevention:** in this Deliverable 3.2, only **1% of the flammable area** was used for preventive infrastructure, adopting the percentage indicated in the prevention plans implemented in the area. However, this area is clearly limited to have a real effect on the fire regime. It would therefore be interesting to replicate the analysis by testing scenarios involving an increase in the surface treated by varying the percentage of treatment (e.g. 1-3-5-10%) out of the total flammable area.
- **Calibration of flammability in intervention areas:** In this Deliverable 3.2, a calibration of Rothermel's (1972) propagation model was used, adopting a set of standard fuel models (Scott and Burgan 2004). Model 184 was used for areas identified as preventive infrastructure. This approach is conservative because the model still allows a relatively fast propagation of the flame front within the intervention areas. It would therefore be interesting to test the effect of choosing alternative standard models to associate with the areas identified as preventive infrastructure (e.g. fuel models 182-181-91).
- **Alternatives for spatial distribution of preventive infrastructures:** In this work, for each scenario (BAU, BIO, TRADE-OFF), a single spatial distribution solution for preventive infrastructures was sought. However, in spatial planning it is useful to consider alternative solutions to ensure due flexibility in the face of limiting conditions on the territory (e.g. geographical features, properties, resources, constraints). Therefore, it would be useful to provide alternative spatialisation solutions for preventive infrastructures that can be chosen at participatory tables in the territory.

The current standard adopted in several European regions to plan fire prevention involves integrating protected areas and Natura 2000 sites into the risk analysis. This approach recognises that a fire is always a problem for a protected area management body regardless of the real impact that fire may have on biodiversity, since a fire represents an administrative burden (e.g. costs, constraints, accessibility). However, this approach poses difficulties for the planner as it is unthinkable, and in many cases undesirable, to 100% prevent a fire from entering a protected area. For prevention activities, resources are limited and must be used in the best possible way according to resource optimisation principles through a multi-criteria analysis that brings different needs to the table: biodiversity conservation, but also civil protection, rural development, agro-sylvo-pastoral production. To deal with this complexity, the following aspects must be considered:

- **Habitats have different sensitivities to fire disturbance:** (i) sensitive habitats: a single disturbance can compromise the functionality of the habitat. In these cases, total protection outside the habitat is necessary to reduce the likelihood of a fire travelling through the habitat. It is necessary therefore to act upstream of the habitat to prevent fire from entering through a network of preventive infrastructures that limit the possibility of fire contagion up to the area to be protected; (ii) at the other extreme, there are habitats that are not very sensitive to fire where even the frequent and intense passage of fire maintains its functionality; (iii) habitats that require a precise fire disturbance regime: in this case, it must not be left the fire phenomenon to chance but must be regulated fire disturbance with active management (e.g. prescribed fire). Planning the fire disturbance regime makes it possible to dose the fire element according to the conservation needs of the habitats, allow fire to have a regulating effect on biomass and prevent the random effect of uncontrolled fires.
- **Identification of targets to protect:** within Natura 2000 areas it is important to identify targets to protect as **islands of senescence** where although the stand may be resilient to fire it must be protected from disturbance in order to ensure the survival over time of old trees and maintain the senescence dynamic

and the presence of certain levels of deadwood and habitat trees. At the same time in some situations fire can be an accelerator in the senescence dynamic, leading the forest to acquire desired attributes such as deadwood levels and number of microhabitats more quickly.

- **Extent of indefinite-ageing areas and islands of senescence:** in some cases, a certain level of indefinite-ageing islands of senescence can be allowed within a protected area. However, the absence of biomass regulation over large areas can lead to the occurrence of large fires with major consequences for the severity within a protected area. An example is the large fire in the Vesuvius National Park in 2017 in Italy, which was managed as a large island of senescence in the absence of biomass regulation management interventions for decades, finally resulting in one of the largest fires in 2017 with 65% of the park area affected with high severity levels and major civil protection problems in the interface areas. The location, **spatial distribution and relative amount of the area with islands of senescence** compared to the burnable area are aspects to be evaluated. In the distribution of islands of senescence, it is necessary to take into account the fire hazard and the preferential trajectories that a fire may take, avoiding alignments, and continuity over large areas that may lead to the release of large amounts of energy with the formation of pyro-cumulus and thus fire behaviour no longer determined by wind and orography, but by its own energy (examples of extreme behaviour - vortices, spotting, downbursts).
- **Fire probability within the protected area:** it must be considered that not all fires can be stopped before they enter a protected area. In this case, action must also be taken within the protected area by increasing, on the one hand, the opportunities for active fighting and, on the other, interventions that increase the resistance and resilience of those stands that are of interest for the conservation of biodiversity.

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6. Annex A

Bibliography consulted for assigning fire sensitivity class to habitats in the landscapes of the two case studies (Italian and Spanish), divided by Natura 2000 (RN2000) habitats. Fire sensitivity classes are divided into (i) Advantaged, (ii) Indifferent or (iii) Sensitive depending on whether the habitat is favored (i.e. benefits from fire passage), neutral (i.e. neither gains nor suffers significant damage with fire passage) or susceptible to fire passage (i.e. fire decreases its resistance and resilience compared to other species).

ID	Replica	Habitat RN2000 Code	Habitat RN2000 Description	DOI	Author	Year	Ecoregion	Country	Locality	Management	Managing agency	Fuel (species)	Fire sensitivity class
1	1	4030	European dry heaths	https://dx.doi.org/10.1016/j.foreco.2012.09.041	Ascoli et al.	2013	Alps conifer and mixed forests	Italy	Piemonte			<i>Calluna vulgaris</i>	Advantaged
2	2	4030	European dry heaths	10.1007/s00035-009-0063-3	Lonati et al.	2009	Alps conifer and mixed forests	Italy	Piemonte			<i>Panicum acuminatum</i> Swartz	Advantaged
3	3	4030	European dry heaths	10.1111/jvs.12100	Velle and Vandvik	2013	Scandinavian coastal conifer forests	Norway	340-km latitudinal gradient along the west coast of Norway, from 60° 70' N, 5° 08' E to 63° 79' N, 9° 39' E			<i>Calluna vulgaris</i>	Advantaged
4		4060	Alpine and Boreal heaths	10.1111/1365-2745.2010.01723.x	Colombarelli et al.	2010	Alps conifer and mixed forests	Switzerland	Gouille, Rion Lake			<i>Juniperus nana</i>	Advantaged
5		4070	Bushes with <i>Pinus mugo</i> and <i>Rhododendron hirsutum</i> (Mugo-Rhododendron heath)	http://dx.doi.org/10.1016/j.quaascr.2014.02.023	Leys et al.	2014	Alps conifer and mixed forests	Italy	Dolomiti, Parco Naturale di Paneveggio, lago di Colbricon inferiore			<i>Pinus mugo</i>	Sensitive
6		4090	Endemic oro-Mediterranean heaths with gorse	https://doi.org/10.3390/plants10040484	Lombana et al.	2024	Tyrrhenian-Adriatic sclerophyllous and mixed forests	Italy	Sardinia			<i>Astragalus</i> L.	Indifferent
7		5110	Stable xerothermophilous formations with <i>Buxus sempervirens</i> on rock slopes (Berberidion p.p.)	https://doi.org/10.1016/j.schres.2018.01.227	Casals et al.	2018	Iberian sclerophyllous and semi-deciduous forests	Spain	Llobera and Madrona, Pyrenees			<i>Buxus</i> s.	Sensitive
8		5130	<i>Juniperus communis</i> formations on heaths or calcareous grasslands	https://doi.org/10.3390/fore6010004	Blanco-Sacristán et al.	2022	Iberian conifer forests	Spain	Sierra Nevada		Natural Park	<i>Juniperus communis</i>	Sensitive
9		5210	Arborescent maternal with <i>Juniperus spp.</i>	https://doi.org/10.3390/fore6010004	Blanco-Sacristán et al.	2022	Iberian conifer forests	Spain	Sierra Nevada	Yes	Natural Park	<i>Juniperus communis</i>	Sensitive
10		6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (* important orchid sites)	https://doi.org/10.3390/agronomy11010006	Nota et al.	2020	Alps conifer and mixed forests	Italy	Piemonte, Oasi Xerothermiche, Val di Susa-Oriente di Chianocco	Yes	ZSC	<i>Festuco-Brometalia</i> grassland species	Indifferent
11		6220	Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea	10.1111/avsc.12418	Villader et al.	2018	Northeast Spain and Southern France Mediterranean forests	France	Sud-est France	Yes	Pastures	<i>Brachypodium</i> and Thero-Brachypodietea species	Advantaged
12		6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinietum caeruleum)	10.1016/j.actao.2005.05.008	Brys et al.	2005	European Atlantic mixed forests	Belgium	Kalmthoutse Heide			<i>Molinia caerulea</i>	Advantaged
13		7110	Active raised bogs	https://doi.org/10.1080/17550874.2017.1394394	Grau-Andrés et al.	2017	Celtic broadleaf forests	Scotland	Brachhead Moss	Yes	Prescribed fire for pastures renewal	<i>Sphagnum</i> spp.	Indifferent
14		7120	Degraded raised bogs still capable of natural regeneration	https://doi.org/10.1080/17550874.2017.1394394	Grau-Andrés et al.	2017	Celtic broadleaf forests	Scotland	Brachhead Moss	Yes	Prescribed fire for pastures renewal	<i>Sphagnum</i> spp.	Indifferent
15		7140	Transition mires and quaking bogs	10.1002/mr.2953	Milligan et al.	2018	Celtic broadleaf forests	England	Moor House National Nature Reserve	Yes	Natural Reserve	<i>Sphagnum</i> spp. and <i>Eriophorum</i>	Indifferent
16		7210	Calcareous fens with <i>Cladium mariscus</i> and species of the Caricion davallianae	https://doi.org/10.1007/s10530-023-0163-8	Link et al.	2023	Mid-Atlantic US coastal savannas	USA	Lake drummond			<i>Phragmites australis</i>	Sensitive
17		9110	Luzulo-Fagetum beech forests	http://dx.doi.org/10.1017/WF15127	Maringer et al.	2016	Alps conifer and mixed forests	Italy/ Switzerland	Piemonte/Ticino			<i>Fagus sylvatica</i> individuals and shrub layer	Sensitive
18		9130	Aspen-Fagetum beech forests	https://doi.org/10.1007/s10694-023-01525-1	Misic et al.	2024	Dinaric Mountains mixed forests	Serbia	Parco nazionale di Tara	Yes	National Park	<i>Abies alba</i> e <i>Picea abies</i>	Sensitive
19		9140	Medio-European subalpine beech woods with <i>Acer</i> and <i>Rumex arifolius</i>	http://dx.doi.org/10.1017/WF15127	Maringer et al.	2016	Alps conifer and mixed forests	Italy/ Switzerland	Piemonte/Ticino			<i>Fagus sylvatica</i> individuals and shrub layer	Indifferent
20		9150	Medio-European limestone beech forests of the Cephalantho-Fagetum	http://dx.doi.org/10.1017/WF15127	Maringer et al.	2016	Alps conifer and mixed forests	Italy/ Switzerland	Piemonte/Ticino			<i>Fagus sylvatica</i> individuals and shrub layer	Indifferent
21		9160	Sub-Atlantic and medio-European oak or oak-bornbeam forests of the Carpinion betuli	https://doi.org/10.1051/forest/2005112	Reyes et al.	2005	Cantabrian mixed forests	Spain	Coruna			<i>Quercus Robur</i>	Indifferent
22		91E0	Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> (Alno-Padion, Alnion incanae, Salicetum albae)	http://dx.doi.org/10.1016/j.foreco.2014.11.017	Kaczynski et al.	2015	Colorado Rockies forests	USA, Colorado	Rocky Mountain National Park	Yes	National Park	<i>Salix</i> , <i>Alnus</i> and <i>Betula</i>	Indifferent
23		91H0	Pannonic woods with <i>Quercus pubescens</i>	https://doi.org/10.1093/treephys/tpaa030	Grizar et al.	2020	Pannonian mixed forests	Slovenia	Podgoroski Kras	No		<i>Quercus pubescens</i>	Advantaged
24		91F0	Riparian mixed forests of <i>Quercus robur</i> , <i>Ulmus laevis</i> and <i>Ulmus minor</i> , <i>Fraxinus excelsior</i> or <i>Fraxinus angustifolia</i> , along the great rivers (Ulmion minoris)	http://dx.doi.org/10.1016/j.foreco.2014.11.017	Kaczynski et al.	2015	Colorado Rockies forests	USA, Colorado	Rocky Mountain National Park	Yes	Natural Park	<i>Salix</i> , <i>Alnus</i> and <i>Betula</i>	Indifferent
25	1	9260	Castanea sativa woods	10.1016/j.flora.2011.07.016	Maringer et al.	2012	Alps conifer and mixed forests	Switzerland	Ticino			<i>Castanea sativa</i> individuals	Advantaged
26	2	9260	Castanea sativa woods	10.1016/j.FORECO.2006.08.316	Catry et al.	2006	Alps conifer and mixed forests	Portugal	30 km from Lisbona	Yes	Protected area	<i>Castanea sativa</i>	Advantaged
27		92A0	<i>Salix alba</i> and <i>Populus alba</i> galleries	10.1007/s11517-009-0008-z	Stromberg and Rychenec	2009		USA, Arizona	San Pedro river	Yes	Natural Park	<i>Salix</i> , <i>Populus</i>	Indifferent
28		9340	<i>Quercus ilex</i> and <i>Quercus rotundifolia</i> forests	https://doi.org/10.3390/fore6080286	Parra and Hinojosa	2023	Iberian sclerophyllous and semi-deciduous forests	Spain	Central Spain			<i>Quercus ilex</i> adult individuals and abundant leaves litter layer	Advantaged
29	1	9410	Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea)	http://dx.doi.org/10.2307/3235616	Engelmark	1993	Scandinavian and Russian taiga	Sweden	Parco Naturale Reivo	Yes	Integral Reserve	<i>Vaccinium</i> herbaceous layer and <i>Picea abies</i> trees	Indifferent
30	2	9410	Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea)	https://doi.org/10.1111/1554-109X.2009.01094.x	de Chantal et al.	2009	Scandinavian and Russian taiga	Finland	Southern Finland	Yes		<i>Picea abies</i>	Sensitive
31	1	9420	Alpine <i>Larix decidua</i> and/or <i>Pinus cembra</i> forests	10.1111/j.1365-2745.2009.01518.x	Gemies et al.	2009	Alps conifer and mixed forests	France	Maurienne valley	No		<i>Pinus cembra</i> and <i>Larix decidua</i> wood residues and litter layer	Advantaged
32	2	9420	Alpine <i>Larix decidua</i> and/or <i>Pinus cembra</i> forests	10.1007/s10564-017-9591-7	Moris et al.	2017	Alps conifer and mixed forests	Italy	Piedmont and Aosta Valley, and the French department of Hautes Alpes in the western European Alps	No		Montane and subalpine forests are dominated by <i>Fagus sylvatica</i> , <i>Pinus sylvestris</i> , <i>Abies alba</i> , <i>Picea abies</i> and <i>Larix decidua</i> , and to a lesser extent by <i>Pinus uncinata</i> , <i>Pinus cembra</i> and broadleaved species	Advantaged
33	3	9420	Alpine <i>Larix decidua</i> and/or <i>Pinus cembra</i> forests	https://doi.org/10.1890/07.1740.1	Gemies et al.	2009	Alps conifer and mixed forests	France	Savoy, central French Alps			<i>Pinus cembra</i> , <i>P. uncinata</i> , <i>Larix decidua</i> , and <i>Picea abies</i> , with understorey vegetation of <i>Amorpha sibirica</i> Lodiger ex Burgsdorff, <i>Vaccinium</i> spp., and <i>Rhododendron ferrugineum</i>	Sensitive
34		9540	Mediterranean pine forests with endemic Mesogean pines	doi:10.1016/j.actao.2006.05.010	Blank et al.	2006	Iberian sclerophyllous and semi-deciduous forests	Spain	Murcia, Sierra de Ricote	No	20 years of abandonment	<i>Pinus halepensis</i> and other Mediterranean pines	Advantaged