Islands for Biodiversity intervention protocol

WP3 – Tools for CNF management

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1. Premise

A typical natural forest ecosystem can be described using a number of key ecological qualities[12,32,33]. These include:

- Diversity of trees, species and habitats,
- Nativeness,
- Forest stand structure (including different-sized forest gaps, diverse tree ages or diameters and vertical structure),
- Microhabitats of the living trees,
- Maturity of living trees and diversity of age classes,
- Presence of deadwood,
- Forest dynamics,
- Continuity in time of forest cover,
- Continuity in space, connectivity and large scales.

The combination and complexity of these key characteristics—none of which are exclusive, mandatory, or binary[21]—play a crucial role in determining the vulnerability, resilience, and adaptive capacity of forests. It is important to note that different forest types may be shaped by different dominant characteristics, and that, for each characteristic, more specific thresholds can be defined according to forest type and climatic conditions (see e.g: Peterken, 1996[27]).

However, in general, forests composed of more tree species are often richer in biodiversity, more resilient and more functionally diverse[14,34]. The presence and diversification of structural elements such as dead wood, microhabitats, senescent trees, forest gaps of different sizes, etc.) contribute to increasing and enhancing forest biodiversity, and in turn, biodiversity positively influences ecosystem functions and services, including CO_2 absorption in terrestrial ecosystems[25]. Continuity in time of forest cover has strong implications on soil processes and the occurrence of species with low dispersion rates. Large scales enable movement of species and genes, provide more flexibility for adaptation and recovery from threats (resilience). Large scale conservation and maintaining or restoring connectivity in landscapes is fundamental for the survival of many endangered species [21].

Maintaining or restoring the different components of forest biodiversity requires a comprehensive concept that combines segregative (reserve) and integrative (off-reserve) conservation tools to sustain species within the hotspots of their presence and throughout the matrix, at different spatial and hierarchical scales[5].

In line with these principles, the GoProForMED project implemented ecological networks within the target habitats, which are actively managed for timber production. The objective of the ecological network is to create a permanent system for the preservation of biological diversity and natural dynamic processes that maintain the vitality and functionality of the project's target habitats. This approach integrates several objectives of forest management, in particular the conservation aspect, fire risk prevention, to be reconciled with the production aspect.

The ecological network, located in the forest matrix, consists of Core Areas, Islands for Biodiversity and Habitat Trees. For a description of the planning, characterisation and materialisation of the ecological network, please refer to the "Core Areas identification protocol" (version updated to 10.07.2024) and to the "*Islands for Biodiversity and Habitat trees identification protocol*" (version updated to 23.07.2024).

In brief:

- **Core Areas (CA)** are areas characterised, in relative terms with respect to the forest stand, by a high functional and qualitative value for the conservation of biodiversity, which constitute the nodes of the ecological network. The function of the Core Area is that of a biodiversity hotspot and of a source of diffusion of mobile species;
- **Islands for Biodiversity (IB)**, within the project, are connecting areas between the Core Areas. The IBs may already present conditions of high structural complexity (in terms of large trees, tree microhabitats, deadwood at different dacey stages, open areas, etc.) and thus contribute to increasing the degree of naturalness of the forest system, and to improving the overall conditions necessary for the conservation of biodiversity;
- **Habitat Tree (HT)**, within the project, have the function of stepping stones to strengthen the connection between IBs and Core Area.

In the logic of the project, the Core Areas are considered as biodiversity hotspots, to be destined for natural evolution. No intervention is therefore planned.

On the other hand, the Islands for Biodiversity, having been selected mainly on the basis of spatial criteria, have varying ecological starting qualities.

The aim of the document is to illustrate the approach, methods and types of intervention to maintain or improve the structural complexity of IBs.

The interventions proposed for IBs take into account the natural dynamics of ecosystems and aim to favour the formation of mature and complex forest communities that support high specific biodiversity. This silvicultural approach considers the characteristics and role of each tree in the context of the natural dynamics of the forest.

2. Silvicultural Objectives for the Biodiversity Islands

Based on the foreword, the silvicultural objectives of Biodiversity Islands are to foster the presence of large trees, habitat trees, open spaces rich in flowering herbaceous and shrub species, significant volumes of deadwood at various stages of decay, and a high degree of both species and structural diversity.

Management interventions are carefully tailored to initiate or enhance natural processes that reinforce the ecological role of Biodiversity Islands as stepping-stones across the landscape.

In areas where these key features are already well established, natural evolution is allowed to proceed with minimal interference—interventions, if needed, are limited to encouraging the formation of new deadwood to ensure a continuous gradient of decomposition stages.

In contrast, in areas where such features are absent or underdeveloped, targeted interventions are implemented with the following **aims**:

OB1. Aim for a structure of maximum theoretical functionality

OB2. Promoting the presence of Very Large Trees (VLTs)

OB3. Favour the presence of habitat trees

OB4. Favour the specific diversity of the forest

OB5. Favour a heterogeneous vertical structure

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

OB7. Increase the amount of laying and standing deadwood

The objectives listed above are detailed below, and for each one the management tools that can be used to achieve them are indicated.

OB1. Aim for a structure of maximum theoretical functionality. **The Energy Equivalence Principle**[31] represents an application of the allometric approach that enables the quantification of how much a forest's current structural condition deviates from its theoretical maximum functional state. This model serves as a general and universally applicable tool for all forest types (see BOX 1).

Using this model, one can estimate the ideal diameter distribution of a forest stand that would optimize resource use similarly to a naturally mature forest. The project's silvicultural interventions are designed to guide forest stands toward this more complex structure, as defined by the model's reference diameter distributions for each of the four target habitats.

In order to make this criterion more understandable and easier to apply, reasoning on structure is carried out on the basis of 4 size categories:

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)

Saplings—young, small to medium-sized trees falling within the 10 to 15 cm diameter classes—along with **Poles** (medium-sized trees in the 20 to 35 cm diameter classes), constitute the **dynamic component** of the forest. These trees are the most responsive to silvicultural treatments, as their development can be significantly influenced by targeted interventions.

For **medium to large trees**, referred to as **Large**, selective actions may be planned to enhance the presence of large deadwood. However, due to their considerable size and the general scarcity of such trees in Mediterranean forest ecosystems, these interventions must be carefully targeted and minimal to avoid compromising this important structural class.

Trees in the **Very Large** category (DBH > 60 cm) are primarily subject to **conservation measures**, as they possess high ecological and landscape value. Their preservation is critical to maintaining habitat complexity and continuity.

By comparing the **actual diameter distribution** of a forest stand—determined through structural surveys of the Biodiversity Islands—with the **reference distribution** provided by the *Energy Equivalence Principle,* it is possible to design interventions that specify the number of trees per hectare to be felled or ring-barked.

This process involves identifying **overrepresented (supernumerary)** and **underrepresented (subnumerary)** diameter classes. Supernumerary classes are reduced through selective cutting or ring barking, while subnumerary classes are preserved and encouraged. When selecting individuals for intervention, preference is generally given to the **largest trees within a class** if the next larger class is underrepresented, in order to promote structural progression toward the target distribution.

In stands where **Saplings are underrepresented**, interventions should focus on **initiating or supporting natural regeneration processes**, including the development of existing regeneration nuclei.

BOX 1 – The application of the Energy Equivalence Principle (EEP) in the Montes Forest

Within a forest, the assemblage of trees of varying diameters reflects the dynamic interplay of birth and mortality processes over space and time—this forms what is known as the **forest structure**, a key ecological attribute of any forest community.

From a theoretical standpoint, it is possible to predict the size distribution of individuals within such a community—one that optimally utilizes resources like light and water—by applying principles from statistical mechanics to a simplified system. This mirrors the resource dynamics observed in mature, structurally complex forests.

The **Energy Equivalence Principle** is a universal allometric model designed to predict the ideal diameter distribution curve of a forest capable of fully utilizing available resources. It assumes that each tree's resource consumption is proportional to the size of its canopy. The resulting distribution curve represents the **optimal forest structure**—a benchmark for maximum functional conditions.

As part of the **LIFE GoProFor Med** project, the EEP is being applied to the four target forest habitats to define the characteristic reference distribution for each one.

A **pilot application** of the EEP was conducted in **June 2023** at the project site in **Montes (NU, Sardinia, Italy)**, representing **habitat 9340 – Quercus ilex and Quercus rotundifolia forests**. This effort was carried out under the framework of the *Protocol for the Definition of the Degree of Disturbance in Mediterranean Forests* (Model H, Deliverable D3.1 - *Technical and Operational Methodological Report for the Conservation Improvement of the Four Target Habitats*).

The objective of this pilot was to define both the **current structural model** of the analysed forest stands and the **potential structural model**, which can serve as a reference for all forests belonging to habitat 9340.

From the resulting potential model, a **reference diameter distribution** (see Fig. 1) was established. This distribution will guide the planning and implementation of interventions within the **Biodiversity Islands** (Objective 1), ensuring alignment with the optimal structural condition.

Categories	Saplings	Poles	Large	Very large
Diametric classes (cm)	10-15 (7,5-17,5)	20-35 (17,5-37,5)	40-55 (37,5-57,5)	60 + (>57,5)
Potential diametric distribution	53%	36%	8%	3%

Figure 1. Potential diametric distribution for habitat 9340 - Quercus ilex and Quercus rotundifolia forests

OB2. Promoting the presence of Very Large Trees (VLTs). The term 'Large Size Trees' (VLTs) refers to the IBP definition for Mediterranean areas[13], i.e. living trees with a diameter >57.5cm. Large trees play an extraordinary range of crucial ecological roles, influencing the hydrological regime, nutrient cycling and numerous other eco-systemic processes[20]. They also play a crucial role for a wide range of plant and animal species due to their microhabitats, size and large canopies, which offer shelter, food and breeding sites for many species, particularly epiphytic species and cavity-nesting birds and bats[18,23], thus contributing to forest biodiversity[13].

To ensure the achievement of this objective, it is essential to preserve existing trees belonging to the "Very Large" category. In parallel, an intervention is implemented to increase their representation by selecting candidate individuals and promoting their growth through the targeted removal of directly competing trees.

Criteria for Selecting Candidate Trees:

- **Diameter Category "Poles"**
  Preference is given to trees with:
  - A good mechanical stability index (Height/DBH ratio < 80).
  - Well-developed crown depth (at least one-third of the total tree height).
  - An unconstrained, well-balanced crown structure.
- **Diameter Category "Large"**
  Selection is primarily based on the tree’s ability to continue growing if released from competition with surrounding trees.
- **Groups of Two or More Trees**
  When two or more trees form a biogroup, they should be treated as a single functional unit. Interventions should be planned to promote the development of the group as a whole.
- **Additional Cross-cutting Selection Criteria**
  - Include a proportion of minority species (in line with Objective 4), provided they have the potential to reach large dimensions.
  - Prioritize native species located in ecologically strategic positions, such as the edges of open areas or sites with specific soil conditions.

OB3. Favour the presence of habitat trees. Within the project a Habitat Tree (HT) is defined as "a standing living tree that, in its current state, bears either":

- at least one tree microhabitat (TreM) listed in a list of TreMs identified as "priority" (BOX 2), or
- at least one TreM found to be among the least frequent at site level, or
- at least 3 different TreMs

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 life cycle[6,7,11]. Correctly identifying, protecting and managing these trees is essential for preserving the ecological function and structural complexity of forests in the long term.

BOX 2 – Tree microhabitat

Definition (TreM): a distinct, well delineated structure occurring on living or standing dead trees, that constitutes a particular and essential substrates or life site for species or species communities during at least a part of their life cycle to develop, feed, shelter or breed (Larrieu et al. 2018).

Priority TreMs types
Grouped into the 7 forms identified da Bütler et al. 2020, following Larrieu et al. 2018.
All seven types[7] are represented by at least one microhabitat.

1) **Cavities:**
   - Woodpecker "Flute"
   - Trunk-base rot-hole (closed top, ground contact)
   - Trunk rot-hole (closed top, no ground contact)
   - Semi-open trunk rot-holes
   - Chimney trunk-base rot-hole (in contact with the ground)
   - Chimney trunk rot-hole with no ground contact
   - Bark-lined trunk concavity
   - Hollow branches
2) **Injuries and exposed wood:**
   - Lightning scar
   - Fire scar
   - Bark shelter
   - Bark pocket
   - Crack
   - Fork split at the intersection
3) **Crown deadwood:**
   - Dead top
4) **Excrescences:**
   - Burr
   - Canker
5) **Fungal fruiting bodies and slime moulds:**
   - Perennial polypore
   - Annual polypore
   - Pulpy agaric
   - Large pyrenomycete
6) **Epiphytic and epixylic structures:**
   - Bark microsoil
   - Invertebrate nests
7) **Fresh exudates:**
   - Sap run

Given that in the course of the intervention the utmost attention must be paid to habitat trees, identifying them and assessing their current and potential effectiveness, selective thinning can also be carried out in favour of habitat trees. This is done with the aim, for example, of guaranteeing a longer survival period or to determine structural diversifications of the stand hinged on their presence.

Thus, intervention can be envisaged against the direct competitors of subjected/dominated habitat trees in order to favour their viability by reducing competitors, or to free fractions of deadwood in the canopy in order to increase the degree of illumination, or, again, to strongly reduce the density of the forest in contiguity with TreMs-rich habitat trees that are home to birds or bats, so as to make them more favoured by these species. **Please note**: the elimination of competitors in favour of the habitat tree must, however, take into account the types of DMH present. Indeed, some of them require shady conditions. In this case, the habitat tree only needs to be preserved, without the need to cut the competitors, which provide the necessary shading conditions for those specific DMHs.

Finally, the analyses carried out in WP02 of the project showed that there is a potential connection between habitat trees and plants that, in the previous cropping cycle, acted as 'standars'. Therefore, it is recommended that these trees also be included among the target plants, even if they are not currently classified as habitat trees. These trees are to be considered as potential habitat trees and, therefore, silvicultural interventions can be envisaged for them in order to favour their vitality and permanence in the forest.

OB4. Favour the specific diversity of the forest. Tree species composition of forest stands have been shown to be key drivers of forest-associated biodiversity in several studies[1,26]. Specific diversity ensures a wider variety of fruits, seeds, flowers and foliage available as food sources for wildlife[13]. Furthermore, many studies have provided ample evidence that trees biodiversity can influence key ecosystem processes such as biomass production, nutrient cycling and pest regulation[8,13]. Finally, there is a positive relationship between specific diversity and resilience, with more diverse systems exhibiting less disturbance-induced variability[30].

In order to encourage a specific mix in the stand, all trees belonging to sporadically present species must be reteained. Furthermore, in the case of trees belonging to these species characterised by good vigour, these can be favoured through selective thinning.

OB5. Favour a heterogeneous vertical structure. Forest stands naturally present a range and complexity of structural factors, including size and diametric diversity of trees and vertical structure[21]. The diversity and development of vertical strata closely influence forest biodiversity, creating diverse ecological conditions and niches that are preferentially used by different plant species, animals and microorganisms[3,13,28].

To promote a **well-differentiated vertical forest structure**, interventions targeting selected elite trees should take the form of **crown thinning** (also known as **thinning from above**). This involves removing **dominant competitors** or trees occupying the same canopy layer, while **leaving the lower, suppressed layers untouched**.

When **minor species** tend to occupy the lower strata, it may be advantageous to **concentrate the thinning efforts within the dominant canopy layer**, selectively and in **small sections**. This approach helps create **irregular canopy openings**, which stimulate the growth and expansion of the remaining trees' crowns into the newly available space, thereby enhancing vertical complexity and fostering a more structurally diverse stand.

OB6. Favour the presence of open areas and flowering herbaceous and shrub species. Open areas in forests increase the landscape diversity by influencing the composition and abundance of insect[10]. Forest species facultatively utilise these gaps for food resources, due to an increased presence of blooms, or cluster there for reproduction[9,13,15,17]. Large open areas are crucial for increasing biodiversity, while smaller areas are preferable for preserving species[10].

To enhance light availability at ground level and encourage the growth of flowering herbaceous and shrub species, interventions should ensure the creation of open areas totaling 200–400 m^2 per hectare, ideally distributed across two separate units. This target includes any pre-existing open spaces and refers specifically to crown-free areas, not areas defined by the spacing between tree trunks.

The creation of open areas represents a disturbance to the ecosystem and should therefore be carried out with minimal impact, carefully selecting the starting points for generating these environments (for example, choosing areas where herbaceous species are already present, even if in limited quantity). Recommended strategies include expanding existing edges, initiating from a small canopy gap and progressively enlarging it in the direction of the light source, or reducing tree crowns near rocky outcrops.

In the latter case, however, it is necessary to assess each situation individually, considering the orientation of the rocky areas in relation to light exposure and the associated fauna. For instance, if the rocky area faces north, it is likely that the associated species are shade- and moisture-loving, and in such cases, canopy cover should be maintained.

In dense stands, it is advisable to create canopy openings no larger than 100 square meters, accompanied by a series of lighter thinnings around the gap to maximize the ground-level light gradient.

In the presence of non-native species, the feasibility of this type of intervention should be carefully evaluated to avoid creating conditions that favor their proliferation.

Furthermore, it is recommended to avoid opening clearings in young stands, as this may result in coppice regrowth from stumps rather than the establishment of flowering herbaceous species.

OB7. Increase the amount of laying and standing deadwood. It is estimated that between 20 and 40% of forest plants, animals and fungi depend on dead or dying wood in at least one stage of their life[4,13]. Maintaining different qualities of deadwood in terms of tree species, diameter, decay class and type (standing or laying) has a positive effect on the conservation of saproxylic species communities[19]. Furthermore, deadwood 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[19]. Regarding the size of deadwood, larger sizes have been identified as essential for the conservation of saproxylic species, for several reasons: being more heterogeneous they offer more ecological niches and microhabitats, which in turn influence the diversity of saproxylic species[19]; size influences the stability of microclimatic conditions and the availability of the resource, as large deadwood decomposes more slowly, remaining available for longer, influencing larval development and ensuring the development of different stages of decomposition[16,24]; large standing deadwood is important for bats and birds, which exploit these structural elements for feeding and nesting or roosting[29]; furthermore, large elements are normally scarce in managed forests, and it becomes crucial to preserve them[16,19].

Within the project, a **minimum diametric threshold of at least 17.5 cm** is considered[13] and **a target quantity of deadwood of at least 20 m^3/ha**[22] is aimed for, gross of existing deadwood and taking into account the intervention limits determined by the application of the forest's potential natural distribution (OB.1) and the impact limits imposed for each size category (see section 3).

The **interventions planned within the Biodiversity Islands** do **not include timber extraction**. All trees selected for removal with a **DBH greater than 17.5 cm** will instead contribute to the **quota of deadwood**. During marking operations, it is strongly recommended to manage cuts and girdling in a way that ensures maximum heterogeneity in the distribution of the material. To this end, it is advisable to vary density by placing deadwood both in accumulations and as isolated individuals; modulate light exposure by alternating between sunny and shaded areas; diversify microclimatic conditions by intervening in both moist hollows and drier ridges; structure spatial distribution by favoring irregular concentrations over uniform layouts; and finally, differentiate the types of deadwood by including both standing and fallen trees.

Ring barking (see BOX 3) may be used as an alternative to felling, especially when a gradual decay process is preferred. Depending on the technique applied, the decomposition timeline can be longer or shorter than that resulting from conventional cutting.

This approach offers several benefits:

- It avoids sudden release effects that may destabilize nearby elite trees;
- It minimizes the risk of mechanical damage to elite trees during felling operations;
- It can also be used on senescent trees, even of large size, to accelerate their natural decay process and enrich structural diversity.

In **highly frequented areas**—such as recreational zones, trails, or footpaths—**standing deadwood may pose safety hazards**. In such cases, it is advisable to fell the tree and leave it on the ground, ensuring both ecological benefit and public safety.

To **increase the diversity of lying deadwood** and contribute to erosion control, trees may be **cut at a height of approximately 1 meter** above ground.

BOX 3 – Types of ring barking

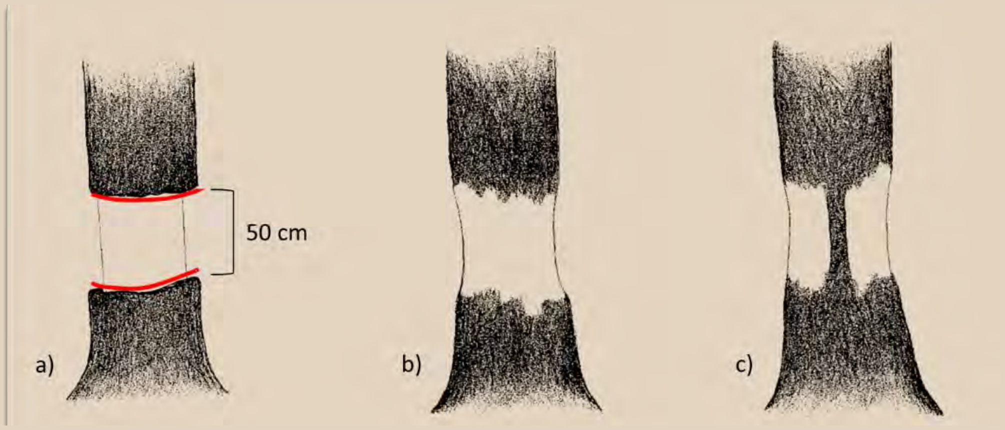
Ring barking consists of removing the outer layers of a portion of the trunk (outer bark and phloem) down to the *cambium*, with the aim of limiting the development and reproduction capacity of the ring barked individual by inducing a slow process of decay.

The main recommended techniques are described below:

a) **Deep ring barking**: this consists of using a chainsaw to make two ring cuts around the trunk in the basal part of the stem, 4-5 cm deep and about 50 cm apart, and removing the entire portion of the trunk with equal thickness to the depth of the cut, present between the two cuts. This type of ring barking causes the plant to decay faster than the two techniques described below.

b) **Superficial ring barking**: this consists of removing a ring of approximately 50 cm in height of the superficial tissues (outer bark and phloem) only. This type of ring barking can be carried out using a billhook or a manual debarker.

c) **Partial ring barking**: this consists of a superficial ring barking with the release of an intact connection strip of the superficial tissues (outer bark and phloem). In this way, the process of decay is further slowed down compared to types a) and b)



3. Intensity of interventions

The silvicultural intervention consists of **selective thinning**, carried out either tree-by-tree or in groups, beginning with the identification of candidate trees—vigorous individuals with well-developed crowns or those of high ecological value, such as habitat trees—followed by the removal of 1 to 3 competing trees for each selected candidate.

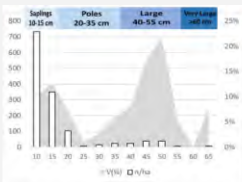
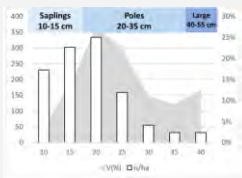
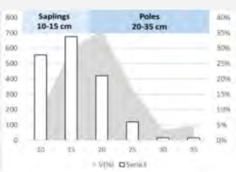
The intensity of the intervention is generally low and adapted on the initial stand structure and ecological conditions.

On Islands for Biodiversity that represent mature stands with good ecological conditions, the intensity of intervention will be reduced to a minimum in order to conserve existing conditions. Punctual interventions may be carried out, if necessary, to achieve one or more of the seven defined objectives.

In contrast, a higher intervention intensity may be applied in Biodiversity Islands where stand volume is predominantly concentrated in the medium-sized trees (20-35 cm DBH).

For stands in an early developmental stage, predominantly composed of individuals in the sapling class, extensive intervention is considered premature. In such cases, targeted actions may be carried out, if necessary, to promote the growth of larger individuals and potential habitat trees.

Table 1. Summary table of the types and intensity of intervention (expressed as % of the number of trees), based on the structural characteristics of the stand

Stand structural characteristics		Intervention type	Intensity
Mature stands, articulated structure Stand volume is more concentrated in the 'large' and 'very large' categories		Preservation of current conditions. Punctual tree-oriented silviculture interventions aimed at achieving Ob. 1-7	0%
Regularly structured adult stands or irregularly structured young-adult stands; Stand volume is more concentrated in the "poles" category		Selective thinning to achieve Ob. 1-7	 10%
Regularly structured young stands; Stand volume is more concentrated in the "saplings" category		Ensure the conservation of all habitat trees and larger plants. Punctual tree-oriented silviculture interventions only when necessary to favour larger trees and habitat trees (OB2 and 3).	0%

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