HANDBOOK OF GOOD PRACTICES IN POST-WILDFIRE MANAGEMENT

How to mitigate or avoid the negative impact of salvage logging in Mediterranean forests

Project
Anifog
The impact of forest fires on animal populations, and post-wildfire management

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PREAMBLE

Since 2010 an increase in wood harvesting for energy purposes has been observed in Europe (sources: Eurostat and RuralCat). One wood source are trees burned by forest fires and harvested by so-called salvage logging. In the vast majority of cases in Europe and North America, logging is carried out a few months to a year after the fire and, on average, 90% of burned wood is cut.[80] Previously, only the tree trunk could be used for sawn timber leaving the branches and the smallest, most badly-shaped stumps in the burned area. Increasingly, with the current growth in the demand for biofuels, the whole tree is being used, exploiting virtually the entire aerial biomass of the burned tree. This massive extraction of biomass from a newly-disturbed ecosystem can create synergistic effects on the environment and its living organisms, which is why many uncertainties still surround this issue. Thus, although the effects of salvage logging have been studied more after fire than after insect epidemics or wind damage, the majority of studies on a global scale have investigated its effects on plant cover regeneration, dead wood and the physical characteristics of the soil. Fewer studies exist on the effects of salvage logging on invasive species, the carbon cycle and other nutrients, soil chemistry, the water regime and river and riparian habitats. In addition, many of these studies have only compared a single modality of logging to unlogged areas instead of comparing the impact among a variety of practices.[80] This makes it difficult to propose a list of practices according to greater or lesser impact.

This **Handbook of Good Practices in Post-wildfire Management** is aimed at forest managers and workers, providing them with a guide on how to mitigate and avoid the negative impacts of salvage logging and enhance the resilience that is naturally present in forest ecosystems in the Mediterranean basin in the face of wildfires.

The main source of information in the compilation of this Handbook has been 172 bibliographic references, mainly scientific articles, monographs and studies conducted in the Mediterranean basin. In particular, the *Web of Science* databases and papers presented at the *Spanish Forestry Congress* have been consulted. The Handbook has been reviewed by various experts in different subjects from research and academic centres, state, regional and provincial administrations, forest owner associations and private companies.

The recommendations set out below are designed to be applied to forestry work carried out in burned forests where wood harvesting (or salvage logging) is practised. They cover **immediate** post-fire actions (or emergency and stabilisation actions just after fire and within the first year after fire), and in the **short term** (or rehabilitation, 1 to 3 years after fire), which are the periods during which wood harvesting is carried out. These recommendations address plant cover regeneration, erosion and surface runoff reduction, soil fertility, conservation of (vertebrate and invertebrate) fauna, reduction of subsequent fire risk and the conservation of the quality of river and riparian habitats. They do not address mid-term restoration actions, such as the recovery of productivity, combustibility reduction, the enhancement of the quality of a mature ecosystem, and the recovery of resilience, with the exception of actions that can be taken in the short term during, or just after, wood harvesting, taking advantage of the presence of workers and machinery in the forest.

The **8 files** are divided into thematic areas, according to the main elements of the environment that can be affected as a result of salvage logging. Each file consists of **two parts**: first, an introduction to the **Fundamentals of post-fire forest management** (p. 10) on which the recommendations are based, and then, the **Good practice files for post-wildfire management** (p. 64), which include recommendations that can be carried out at stand and plot level during the logging process. Our intention is that these two parts can be read independently. To facilitate the connection between both parts (introductory text and good practice file), each theme is represented by a different colour. So, if readers are interested in finding out more about the ecological implications of forest fires and salvage logging, they can focus on the introductory text. But, if they are seeking to reduce the negative impact of post-wildfire forest management, they should consult the good practice files.

The files are numbered 0 al 7 according to the environmental elements involved. One exception to the two-part file is File 0 on *Post-wildfire Management and Planning at Landscape Level*, in which the fundamentals and best practices for the entire burned area are presented together. The **8 file topics** are:

0. Post-wildfire Management and Planning at Landscape Level
1. Plant cover regeneration
2. Reduction of soil erosion
3. Preservation of soil fertility
4. Conservation of invertebrate fauna
5. Conservation of vertebrate fauna
6. Reduction of subsequent fire risk
7. Preservation of the quality of river and riverbank habitats

These topics have been divided into more precise sections (for example, according to dominant tree species), identified by a second number. The “General conditions” section of each topic is numbered 0.

There are **12 groups of recommendations for forestry work** linked to salvage logging for each of these environmental elements, including subsequent tasks and the conditions that affect them, such as climate or slope gradient. These tasks are set out in chronological order: cutting, clearing, site preparation, etc. Recommendations are identified by a letter, from "a" to "l":

a. Whole-tree harvesting
b. Stem-only harvesting/chopped wood
c. No harvesting
d. Optimum time for logging
e. Location of logging sites
f. Logging intensity
g. Clearing
h. Site preparation
i. Climate conditions
j. Sloping land
k. Specific tasks
l. Silvopastoral benefits

The good practice files have been designed for **modular reading** (for specific consultations depending on the reader's objectives or interests). All the files have the same structure to facilitate browsing: 12 groups of recommendations.

TABLE 1 shows the good practice files that contain the information needed to make post-wildfire management recommendations. Thus, for example, recommendation 1.2 d refers to the most suitable time for salvage logging to favour and reduce the impact on plant cover regeneration in non-serotinous pine forests (before fire).

To guide the manager towards the appropriate post-wildfire management recommendations, we suggest consulting the **Recommendation Selection Tool** (p. 54). This is divided into the four main objectives for the burned area and it addresses not only the available means to carry out the work, but also post-fire ecosystem conditions.

Finally, the authors have considered it useful to base these recommendations on evidence from studies and the knowledge of professionals and specialists, without taking into account the **legislation** of a specific territory, so these files can be applicable to the vast majority of woodland ecosystems in the Mediterranean basin.

TABLE 1.
Codes of the recommendations of good practices files in post-wildfire management.

Environmental elements (or topics) Plant cover regeneration	Sections
Plant cover regeneration	General
	Serotinous pines
	Non-serotinous pines
	Holm and deciduous oaks
	Cork oaks
	Understory vegetation
	Conversion to open habitats
Reduction of soil erosion	General
	Pine forests
	Eucalyptus
Preservation of soil fertility	General
	Eucalyptus
Conservation of invertebrate fauna	Soil and litter invertebrates
	Saproxylic invertebrates and wood-boring insects
Conservation of vertebrate fauna	Birds
	Mammals
	Herpetofauna (amphibians and reptiles)
Reduction of subsequent fire risk	General
Preservation of the quality of river and riverbank habitats	Riparian forests and water courses
	Erosion control procedures

	Whole-tree harvesting	Stem-only harvesting / chopped wood	No harvesting	Optimum time for logging	Location of logging sites	Logging intensity	Clearing	Site preparation	Climate conditions	Sloping land	Specific tasks	Silvopastoral benefits
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**
1.0	1.0 a	1.0 b	1.0 c	1.0 d	1.0 e	–	1.0 g	1.0 h	–	–	1.0 k	1.0 l
1.1	1.1 a	1.1 b	1.1 c	1.1 d	G	–	G	1.1 h	–	–	1.1 k	1.1 l
1.2	1.2 a	G	G	1.2 d	G	–	G	1.2 h	–	–	1.2 k	1.2 l
1.3	1.3 a	1.3 b	1.3 c	G	1.3 e	–	G	1.3 h	–	–	1.3 k	1.3 l
1.4	1.4 a	1.4 b	1.4 c	1.4 d	1.4 e	–	1.4 g	1.4 h	–	–	1.4 k	1.4 l
1.5	G	G	G	G	G	–	G	G	–	–	1.5 k	G
1.6	1.6 a	1.6 b	1.6 c	1.6 d	1.6 e	1.6 f	1.6 g	1.6 h	–	–	1.6 k	1.6 l
2.0	2.0 a	2.0 b	2.0 c	2.0 d	2.0 e	2.0 f	2.0 g	2.0 h	2.0 i	2.0 j	2.0 k	2.0 l
2.1	G	G	G	2.1 d	G	G	G	2.1 h	G	G	G	G
2.2	G	G	G	G	G	G	G	2.2 h	G	G	2.2 k	G
3.0	3.0 a	3.0 b	3.0 c	3.0 d	3.0 e	3.0 f	3.0 g	3.0 h	3.0 i	–	–	3.0 l
3.1	G	G	G	G	G	G	G	3.1 h	G	–	3.1 k	G
4.1	4.1 a	4.1 b	4.1 c	4.1 d	4.1 e	4.1 f	–	4.1 h	–	–	4.1 k	4.1 l
4.2	4.2 a	4.2 b	4.2 c	–	4.2 e	4.2 f	–	–	–	–	4.2 k	–
5.1	5.1 a	5.1 b	5.1 c	–	5.1 e	5.1 f	–	–	–	–	5.1 k	5.1 l
5.2	5.2 a	5.2 b	5.2 c	–	5.2 e	–	–	–	–	–	–	–
5.3	5.3 a	5.3 b	5.3 c	–	5.3 e	–	–	–	–	–	5.3 k	–
6.0	6.0 a	6.0 b	6.0 c	–	6.0 e	6.0 f	–	6.0 h	–	–	6.0 k	6.0 l
7.1	7.1 a	7.1 b	7.1 c	7.1 d	7.1 e	7.1 f	7.1 g	7.1 h	7.1 i	7.1 j	7.1 k	7.1 l
7.2	7.2 a	7.2 b	7.2 c	7.2 d	7.2 e	7.2 f	–	7.2 h	7.2 i	7.2 j	7.2 k	–

[G] *indicates situations for which specific recommendations have not been found and the recommendations of the "General" section of that topic are applicable.*
[–] *indicates situations for which specific recommendations have not been found.*

THE BASIC PRINCIPLES FOR POST-WILDFIRE MANAGEMENT

In this section we present the ecological impacts of forest fires and salvage logging on the eight main forest elements. To help link both parts of each file (the basic principles and the good practice files), the two parts are represented by the same name and colour:

One exception is File 0 on *Post-wildfire Management and Planning at Landscape Level*. The basic principles and recommendations for the entire burned area are presented together.

The objectives of this section are: (1) to enhance understanding of what happens during and after a forest fire, and (2) to provide supporting evidence for the good practice recommendations.

0. POST-WILDFIRE MANAGEMENT AND PLANNING AT LANDSCAPE LEVEL

Objective: to mitigate or avoid the large-scale negative impacts caused by salvage logging.

0.1 Post-fire status assessment

Historically, the management of burned forest areas in the Mediterranean basin has involved pine reforestation, or complete pine afforestation,[98] harvesting the burned timber if profitable. Nowadays, the increase in the consumption of forest biomass for energy purposes (in the form of wood chips or pellets) is encouraging whole-tree harvesting in large burned areas, normally with few restoration measures and with logging beginning shortly after fire. However, depending on local conditions, this is not always best practice. When considering post-wildfire salvage logging, forest managers and stakeholders must face a key issue: what are the objectives of this action? The answer depends on two factors: the previously defined objectives for the burned forest area, and the ability to predict how the ecosystem affected by the fire will react.[98]

First, a forest fire should not be a reason for reversing the previously-established objectives for a forest or territory.[81] However, the transformation of the ecosystem as a result of fire may be an opportunity for the environment to be replanted with more resilient, or fire-resistant, plant formations (for example, the conversion of non-serotinous pine stands to resprouting planifolium shrubs), or the maintenance of rare habitats (for example, the creation of grasslands or scrub in regions with excessive forest continuity). All the objectives chosen not only by (public and private) forest owners, but also by society, exceed land ownership boundaries and the area affected by fire. Hence, landscape planning and management that go beyond the plot boundaries and the burned areas are needed.

Second, the response of the ecosystem to fire largely depends on its ecological vulnerability, and on fire severity. It is necessary, therefore, to evaluate the capacity of the burned area to withstand salvage logging and modify it in order not to compromise environmental sustainability. Due to fire and environmental heterogeneity, the Ministry of Agriculture, Food and Environment[1] has proposed a standardised framework for the urgent assessment of environmental vulnerability and fire severity which involves sampling the burned area as soon as possible after fire and always before autumn rainfall.

Sampling is systematic, with a 20m radius of sampling points randomly selected using a square mesh placed over the fire zone to limit subjectivity (TABLE 2). If the topography permits, observations from accessible high points can be added, allowing a more global appraisal of the burned area.

TABLE 2. Recommendations for mesh density and number of sampling points for low-access areas, depending on the extent of the fire.

Fire burned area (ha)	100	500	1.000	2.500	5.000	7.500	10.000
Nffl. of mesh sampling points	50	100	150	300	500	600	650
Nffl. sampling points	6-15		25-50				>50

Source: Alloza, J. A., Garcia, S., Gimeno, T., Baeza, J., Vallejo, R., Rojo, L. & Martínez, A. 2014. Guía técnica para la gestión de montes quemados. Protocolos de actuación para la restauración de zonas quemadas con riesgo de desertificación. 1a ed., Ministerio de Agricultura, Alimentación y Medio Ambiente.

Assessed at the sampling points will be environmental **vulnerability** and fire **severity** for both soil and vegetation (TABLE 3). Any specific impact that facilitates assessment should also be indicated.

Based on the sampling data, **homogenous zones** can be mapped out where vulnerability and severity are similar for each post-wildfire characteristic of the environment. Good practice recommendations to protect, mitigate or restore problems derived from fires are shown for each of these characteristics in one or more of the files (right-hand column of TABLE 3). If vulnerability or severity are high for a specific characteristic, it is important to apply the file's strictest recommendations. On the other hand, if they are low, forestry work with less rigorous protection, mitigation or restoration measures may be carried out. If two post-fire environmental characteristics display different degrees of vulnerability or severity, the strictest recommendations should be implemented as a precaution.

Fire severity, or the degree of disturbance caused by fire to soil and vegetation, can be evaluated and mapped by combining field sampling, existing cartography and the use of multispectral imagery, especially in the case of larger fires. No automated procedure currently exists for this task.[159]

TABLE 3. Environmental vulnerability and fire severity assessment at sampling points.

		Post-wildfire environmental characteristics		Grau de vulnerabilitat i de severitat			Fitxes amb recomanacions de bones pràctiques
				Low	Medium	High	
VULNERABILITY	Soil	**Slope gradient**		< 15%	15-30%	> 30%	2. Soil erosion 7. River/riverbank habitats
		Lithology [a]		Type I	Type II	Type III	2. Soil erosion
		Previous symptoms of erosion	Degree of erosion	Absent/slight	Moderate	Severe	2. Soil erosion 7. River/riverbank habitats
			State of terraces	Good	Partial collapse	Generalised collapse	
			Degree of soil crusting[b]	Absent/slight	Moderate	Severe	
		Soil protection	% bare soil	< 30%	30-60%	> 60%	2. Soil erosion 3. Soil fertility 7. River/riverbank habitats
			Leaf litter thickness	> 3cm	1-3 cm	< 1cm	
	Vegetation	**Response capacity**	Mature CCF forest (serotinous or resprouting)	> 60%	30-60%	< 30%	1. Plant cover regeneration 5. Vertebrates
			Resprouting shrub cover	> 60%	30-60%	< 30%	
			Resprouting grass cover	> 60%	30-60%	< 30%	
		Fire recurrence in last 20 years		0	1	> 1	1. Plant cover regeneration
		Damage by pests		Absent/slight	Moderate	High	4. Invertebrates
SEVERITY	Soil	**Effects on leaf litter**		Intact	Partially burned	Consumed	1. Plant cover regeneration 3. Soil fertility
		Presence of white ash		Absent	Isolated patches	Generalised	1. Plant cover regeneration 3. Soil fertility
	Vegetation	**Trees**		> 50% green canopy	> 50% dry leaves	Consumed canopies	1. Plant cover regeneration 5. Vertebrates
		Scrub		Green leaves	Thin branches consumes	Thick branches consumed	1. Plant cover regeneration 5. Vertebrates
		Herbaceous plants		Green remains	Partially burned	Consumed	1. Plant cover regeneration 5. Vertebrates

[a] Type I: limestone, dolomite, limestone with dolomite, or calcarenite, limestone and sandstone; type II: marlstone, calcarenite, tufa, conglomerate, conglomerate and clay, limestone and marl, flysch, calcarenite and marlstone, dolomite and marlstone, sandstone, slate, schist and quartzite; type III: granite, conglomerate with clay, sand, clay, clay with sand, gypsum, marlstone, clay with marlstone or silt.

[b] Estimated by crust thickness and consistency when dry: slight soil crusting is no more than 2 mm thick and breaks easily; moderate is 2-5 mm, and severe is more than 5 mm and very hard.

Source: adapted from Alloza, J. A., Garcia, S., Gimeno, T., Baeza, J., Vallejo, R., Rojo, L. & Martínez, A. 2014. Guía técnica para la gestión de montes quemados. Protocolos de actuación para la restauración de zonas quemadas con riesgo de desertificación. 1a ed., Ministerio de Agricultura, Alimentación y Medio Ambiente.

0.2 Burned wood retention as a mitigation measure

The main measure available for reducing the impact of salvage logging is the preservation of standing burned trees. **Dead wood retention** should fulfil different objectives and not merely serve commercial purposes. Little information is available on the minimum amount of dead wood to be preserved during logging. This wood retention can be expressed by biomass per surface unit, or according to the proportion of the burned forest area excluded from logging.

To guide the manager in the **amount** of burned wood that should be retained depending on different objectives, standards have been set for mature inland forests in the west of the United States[17] (TABLE 4). These data cannot be extrapolated to Mediterranean forests due to differences in composition, structure and dynamics. However, in the Mediterranean forests of the Apennine Mountains, there are between 7 and 60 tons/ha of large-dimension dead wood[83] after 35 to 50 years, an interval similar to that proposed in TABLE 4. It is important to leave a part of the burned wood after fire since it will take many years for the forest to grow and mature enough to regenerate a considerable volume of wood of these characteristics.

TABLE 4. Optimal (more than 7.5cm diameter) dead wood intervals to be retained after fire.

	Forests in dry, warm areas		Forests in cool and mountain areas	
Objectives	Minimum (stump/ha)	Maximum (stump/ha)	Minimum (stump/ha)	Maximum (stump/ha)
To control risk of subsequent fire	0	56	0	67
To prevent heat transmitted to soil in the case of subsequent fire	0	78	0	90
To maintain forest productivity	11	22	22	56
To preserve biodiversity	6	67	11	67
To preserve the historical significance of the burned tree(s)	11	22	22	60
Recommended global quantity	11	45	22	67

Source: adapted from Brown, J. K., Reinhardt, E. D. & Kramer, K. A. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. General technical report RMRS-GTR-105, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.[16]

Few studies exist on the **quality** of burned wood in Mediterranean ecosystems, and even fewer on its **decomposition**. The most relevant study was carried out in Sierra Nevada (Andalusia, Spain) on maritime pine plantations (at low altitudes, around 1,500 m), black pine (at medium altitudes) and Scots pine (at high altitudes, around 2,000 m). Ten years after fire, trunks (between 5 and 25 cm in diameter) had lost on average 23% of their mass; the least was Scots pine (11%) and the most, black pine (32%). Contrary to studies in other climates, tree stems of greater diameter had decomposed more quickly than those of smaller diameter. This could be caused by the lower surface-to-volume ratio of the thickest stems, enabling greater conservation of wood humidity and, therefore, a greater proliferation of decomposing organisms. This diversity in decomposition speed contributes to the spatial-temporal diversity of dead wood quality.[97]

Another way to measure dead wood retention is the fire **surface area** preserved without logging. For boreal forests in eastern Canada, a committee of experts on the use of burned forests have suggested keeping, at the regional scale, between 15 and 30% of the burned woodland area without logging so that weak dead wood retention in a fire can be compensated by greater retention in another fire in the same region.[100] Evaluation is proposed over a 5-year period. This flexibility does not rule out that standing trees can be retained in each fire in ecologically sensitive areas, for example, next to water courses, or in areas at risk of erosion. Similarly, burned trees can be preserved dispersed among patches of unburned vegetation.

The preservation of **standing dead trees (snags) in clumps** offers more advantages than leaving them scattered. These clumps or strips can cover areas where the soil is most vulnerable, soften the ecotone between the unburned forest and logging area and capture sediments transported in surface runoff from the burned area to water courses. Leaving some trees scattered in the logging strip will enable the preservation of a certain landscape heterogeneity. As a general rule, it is suggested that 90 and 95% of the total amount of dead wood left standing is preserved in clumps, and located according to the good practice files. Between 5 and 10% should remain isolated (scattered in the logging strip).

For more detailed information on the distribution of unharvested dead wood within the fire perimeter, consult CHART 1 and section “0.3 Standing tree preservation areas”.

CHART 1. Biomass availability according to harvesting system.

The harvesting system has a great impact on the possible uses of burned dead wood. Stem-only harvesting is more flexible since it allows the separate use of branches and trunk, and leaves more organic matter (branches and canopies) in the logging strip. In Mediterranean forests, branch biomass accounts for approximately one fifth of the aerial biomass of a tree (excluding the leaves, since they are considered to have been burned in the fire).[25] In other words, the biomass of one whole tree is equivalent to the biomass of the branches of five burned trees. Thus, a logging strip employing whole-tree harvesting leaving one tree in five (excluding the areas of snags in clumps and in isolation) would preserve the same biomass as the same strip using stem-only harvesting (provided the branches were left in situ).

We suggest that, by calculating the number of trees to be cut (excluding clumps of snags or scattered burned trees), one tree in five should be preserved if whole-tree harvesting is carried out. If stem-only harvesting is used, this supplementary retention does not have to be made, but it is recommended that branches are left in piles due to the numerous advantages this practice has. In conditions of sloping land (> 15%) and where soil is vulnerable to risk of erosion, it is advisable to keep a few logs to build erosion barriers combined with a pile of branches.

b

FIGURE 1. Multifunctional piles (anti-erosion, biomass retention and biodiversity protection) in slope areas: May 2017 (a) and February 2018 (b) of a stone pine forest with cork oaks burned in July 2016. **Images:** P. Pons.

Since the distribution of the proposed logging area is independent of land ownership boundaries, the owners of plots with greater burned tree retention would have less income from the sale of burned wood than they are entitled to. To compensate this, we propose distributing income based on the burned woodland area in each plot, rather than on the volume of harvested wood. This system has already been proposed or used after fire in some municipalities. To meet territorial objectives, the manager will have to plan salvage logging and other related activities (such as the construction of erosion control barriers using timber from logging) based on a regional-scale vision and not restricted by land ownership.

Regardless of land boundaries, ecosystem vulnerability and fire severity, certain factors deserve special attention (TABLE 5) and should be considered within the context of the entire burned area and its surrounding landscape.[81,82] Given the recurrence of wildfires in the Mediterranean basin, these considerations should already be included in territorial or forest management planning. The good practice files propose specific actions for the various protection objectives or mitigation measures listed in TABLE 5.

TABLE 5. Objectives for ecological asset protection and measures to mitigate salvage logging impacts.

OBJECTIVES	0. Post-wildfire management and planning at landscape level	1. Plant cover regeneration	2. Reduction of soil erosion	3. Preservation of soil fertility	4. Conservation of invertebrate fauna	5. Conservation of vertebrate fauna	6. Reduction of subsequent fire risk	7. Preservation of the quality of river and riverbank habitats
Protection of important ecological assets								
Protection of special habitats: crags, caves, rocky outcrops, open-habitat species, dry stone constructions, etc.		X			X	X		X
Protection of forest stands (with or without trees) that are rare due to their composition, structure or scarce fragmentation	X	X						X
Protection of places of great biological interest: ecotones, large dead wood sources, habitats of rare species, rare ecosystems, etc.	X	X			X	X		X
Protection of aquatic ecosystems, riparian zones, water catchment areas and temporary ponds								X
Protection of regional corridors and other forms of connectivity	X							
Timing of harvesting to minimise the impact on the environment and on organisms		X	X	X	X	X		X
Mitigation of salvage logging impacts								
Mitigation of the impacts of log hauling and transport		X	X	X				X
Development of objectives at landscape level for specific structural elements: density of standing burned trees (snags) and large trees with hollows, etc.	X	X			X	X	X	X
Consideration of special and temporal logging patterns aggregate/disperse, logging surface area, logging duration, etc.	X	X	X	X	X	X	X	X
Environmental restoration and rehabilitation		X	X	X			X	X
Development or maintenance of fire prevention forestry							X	
Development of management strategies for specific species: rare or endangered species, game species, invasive species, etc.		X			X	X		X

0.3 Standing tree preservation areas

Snag preservation zones are areas within the fire perimeter excluded from wood harvesting, either because of environmental fragility after fire or because of the multitude of environmental services that can be provided if these clumps of standing trees (dead or living) are preserved. Little information is available on the minimum proportion of burned zones that should be left unlogged. The committee of experts on burned forest harvesting in Quebec[100] recommends reserving, at regional level, at least 30% of the burned area, and 15% of the burned area for each fire. Other studies[22,56,78] recommend keeping at least 10% of the trees burned in a fire. Depending on whether the objective is to mitigate logging effects or protect the environment, these snags can remain scattered, in clumps, or in a combination of both distribution patterns, forming a mosaic.

Based on the compiled recommendations, we propose dividing the area within the fire perimeter into four zones:

1st Priority Conservation Area: These are areas where it is essential to prevent machine traffic and the opening of new roads and tracks due to post-fire environmental fragility or to the many environmental services that these areas provide. The 1st priority conservation area should cover at least 10% of the area within the fire perimeter and the places listed in TABLE 6 should be respected. This area must be respected in all fires, whatever the size, because of its great ecological importance.

2nd Priority Conservation Area: These are areas that are less environmentally fragile after fire, where the preservation of snags facilitates the regeneration of the ecosystem. Machine traffic and the opening up of new roads and tracks must be avoided. The size of this area, added to the 1st priority conservation area, should cover at least 20% of the area within the fire perimeter and be applied in fires of more than 10 ha. The list of places where 2nd priority conservation areas should be established can be found in TABLE 6.

Conservation areas for recolonisation: These are aimed at providing the flora and fauna with large burned zones unaltered by humans to enable their survival within the area affected by fire, and they serve as a source of recolonisation. New roads or tracks can be opened up in these areas to gain access to logging strips. Applicable in fires over 100 ha, the size of this area, together with the previous two, should cover at least 30% of the area within the fire perimeter. The places destined for recolonisation are set out in detail in TABLE 6.

Salvage logging zone: This corresponds to the logging strip; in other words, the area where the harvesting of trees burned in the fire is a priority, while always complying with the recommendations set out in the good practice files. Nonetheless, scattered dead wood retention is recommended (TABLE 6).

By preserving standing trees in these four areas within the fire perimeter, the retention of volumes of dead wood similar to those found in Mediterranean forests in natural evolution, and not subject to wood harvesting, would be achieved. This system favours the protection and survival of both soil and surface invertebrates and saproxylic organisms (recommendations 4.1 f and 4.2 f). It also favours the use of the environment by vertebrate fauna (recommendations 5.1 e, 5.2 e and 5.3 e), although the consulted sources do not specify minimum area size or specific locations in relation to standing tree preservation areas. Nonetheless, forestry work should be avoided during the breeding season of birds and mammals (recommendations 5.1 d and 5.2 d., respectively), which tend to coincide with periods when populations of other fauna are more vulnerable. That said, we recommend waiting 4 months from the end of the fire before entering the burned area with machinery, although it is also advisable to wait up to 8 months or even a year (recommendations 2.0 d and 3.0 d) depending on soil vulnerability to erosion and loss of fertility.

TABLE 6. Standing tree (snag) conservation areas.

ZONE	LOCATION AND DIMENSIONS	FILES
1st priority Applicable in all fires	40m-wide strip on both sides of perennial and intermittent water courses and around wetlands and temporary ponds	7.1 e, 7.1 k
	30-60m-wide strip around the entire fire perimeter, downstream	7.1 e
	Areas of soil with high vulnerability to erosion, where soil has been severely burned or where erosion existed before the fire	2.0 e
	Patches of unburned vegetation and unburned litter (which may only measure a few square metres), including any dead trees	1.0 a, 1.0 b, 1.0 c, 1.2 k,
	If there are no unburned vegetation patches, leave 0.5 ha of aggregates or more burned trees without cutting, or leave clumps of 10 to 20 trees	4.1 e
2nd priority Applicable to all fires > 10 ha [a]	30-60m-wide strip around the entire fire perimeter, upstream	7.1 e
	Retention of burned trees in patches of at least 50 m x 100 m	4.1 e, 4.2 e
	Retention of burned trees on all southern slopes with shallow, not very stony soils, and where particles are little aggregated	1.0 e, 2.0 d, 3.0 e
Conservation for recolonisation Applicable to all fires > 100 ha	Retention patches of at least 200 m x 200 m	4.1 e, 4.2 e
	These patches can be located in less suitable areas for wood harvesting (steep slopes), weak standing tree density or small trees, difficult access, soils sensitive to heavy machine traffic) or in areas where specific habitats may be found (crags, caves, rocky terrain, etc.).	
Logging strip	If whole-tree harvesting is used in the logging strip, keep one in every 5 dead trees (whole or with a broken trunk, measuring more than 2 m high in both cases).	5.1 f
	If stem-only harvesting is employed, leaving branches on site, it is not necessary to preserve isolated trees in the logging strip. See Chart 1.	

[a] Since the 1990s, the average surface area of forest fires in European Mediterranean countries is around 10 ha.

Implementing these standards for snag preservation requires global, coordinated management of the burned area. A post-fire coordination board can be a suitable tool and has already been used in some fires in Spain, especially in the Valencian Community under the aegis of the Ministry of Agriculture, Environment, Climate Change and Rural Development. Common problems are identified, working groups facilitating information exchange are promoted, and decision-making is carried out in an open, flexible and effective way.[30] Forest owner associations, forestry companies, town councils, regional and/or state forestry services, scientific staff from forestry or environmental research centres and all the other stakeholders interested in the management and use of the territory, such as hunting associations and forest defence groups, should be present. Participants in the coordination board should decide on the forest model wanted for the affected territory as well as the measures to be taken for restoration and to prevent a similar fire from happening again. Snag preservation areas could also be demarcated and compensations for forest owners who voluntarily offer zones free from logging can be decided. To encourage this, revenue from the sale of wood could be distributed based on the area of burned trees in each plot, rather than on the volume of harvested wood. It is important that the board's decisions receive financial backing, especially if there is a need to compensate owners of plots where the agreed restrictions on harvesting reduce the benefits that they would otherwise have obtained.

1. PLANT COVER REGENERATION

Objective: to accelerate post-wildfire plant cover regeneration

1.0 General conditions

Regenerating plant cover after fire not only allows wood and non-wood production to resume, but it also reduces erosion (see file "2. Reduction of soil erosion") and nutrient loss, protects the humic complex and soil structure (see file "3. Preservation of soil fertility"), recovers the conditions necessary for wild life (see files "4. Conservation of invertebrate fauna" and "5. Conservation of vertebrate fauna"), and speeds up the return of ecosystem services.[102,158] In the Mediterranean basin, different groups of trees have different resistance or resilience strategies to fire. The most suitable practices to speed up plant cover regeneration depend, therefore, on the composition of the burned stand according to whether it contained mainly:

- serotinous pines (especially *Pinus halepensis, P. pinaster, P. brutia*)
- non-serotinous pines (especially *Pinus pinea, P. nigra, P. sylvestris*)
- *Quercus* oaks (except *Quercus suber*)
- cork oaks (*Quercus suber*)

In addition, speeding up the recovery of understory plant cover (shrubs, grasses and bryophytes) must also be taken into consideration, given the advantages already mentioned. The fire disturbance can also be seen as an opportunity to convert burned wooded areas into open spaces.

Generally speaking, salvage logging can slow down plant cover regeneration. Two years after fire in logged stands, there is less wealth of plant species and/or less diversity, less total plant cover and a greater proportion of plant species, compared to unlogged stands.[53,167] Plant cover by species reproduced by seeds is significantly lower in logged than in unlogged stands.[78] If logging debris is left, plant cover regeneration is assisted by wood that has not been shredded or chipped.[78] In the Mediterranean climate, characterised by high water stress in summer, the preservation of burned wood decreases temperature extremes between day and night by between 1 and 2°C,[47] and favours greater soil moisture retention,[56] which can facilitate the establishment of new plant cover.

Plant cover recovery is faster if the stand has sprouting species (resprouters) as opposed to species that reproduce by seed (germinators). Not only do the latter grow more slowly and are more sensitive to water stress (due to a less developed root system), but they are also more affected by salvage logging given that their saplings are more vulnerable to being trampled.[78]

1.1 Serotinous pines

These pine species have cones where seeds may remain for over a year without losing their germination capacity, and will only be dispersed when certain environmental conditions occur, such as the heat of a fire.[34] In the case of the species dealt with here, the high temperatures during a fire can encourage serotinous pine cones to open, and the germination capacity of the pine seeds, which remain protected inside, is not damaged.[93] Moreover, pine seed banks on the ground resist the passage of the flames,[158] although these banks are usually scarce.[45]

Thus, following a fire in a mature **Aleppo pine** forest with only 250 pines/ha, the abundance of viable pine seeds in the canopy seed bank is sufficient to ensure the regeneration of the pine wood, provided that the climate conditions are suitable and able to withstand a high degree of predation.[93] Germination mainly occurs during the autumn and winter after fire when densities of between 70,000 and 90,000 saplings/ha can be achieved. During the second autumn after fire, a new, but much less abundant, germination may take place.[94] In the case of **maritime pine**, germination in the outer regions of the Iberian Peninsula begins in winter and by the beginning of spring, 88% of germination has taken place (although it may be delayed until May in the centre of the Iberian Peninsula), giving rise to a density of 35,000 trees/ha.[45]

Thanks to their serotinous cones, these pine species are highly resistant to fire. They normally do not have regeneration problems after fire, unless a new fire occurs when they are still at the stage of immaturity.[152] This stage, which lasts between 20 and 30 years (or at best, only 15) is the minimum time necessary for the regenerated pine wood to reach maturity and begin to produce an abundant supply of pine cones.[158] Fire recurrence alters the plant composition of pine woods.[152]

Only a few studies have found that salvage logging and debris manipulation can hinder the regeneration of these pine species. In general, whole-tree harvesting and manual cutting are compatible with the natural post-fire regeneration of mature pinewoods.[9] In the centre of the Iberian Peninsula, a 45% survival rate of **maritime pine** saplings was observed when logging took place during autumn, before germination; a 30% survival rate when no logging was done, and a 20% survival rate when logging took place at the end of autumn or winter when the pine seeds had already germinated. Despite the partial destruction of the saplings, the density that survive is sufficiently high to construct a stand of 2,000 trees/ha 10 years after fire.[19] Moreover, the decrease in sprout density caused by machinery may delay the emergence of intraspecific competition in the regenerated maritime pinewood.[19,152] However, fire severity, low proportions of serotinous pine cones and conditions of water stress may limit the establishment of maritime pine woods. It would appear that these three factors have a greater impact on the post-wildfire regeneration of a pine stand than the presence or absence of salvage logging.[19] On the other hand, when harvesting is carried out after a second fire, the negative impact of salvage log-

FIGURE 2. Aleppo pine forest after whole tree harvesting (a); young Aleppo pine forest where the trees have been felled and chopped without harvesting (b). This fact allows spreading burnt wood on the ground. **Images**: P. Pons i J.M. Bas.

ging does exist, via the synergistic effects of the fire, on the regenerated pinewood (although logging has a positive effect on the regeneration of resprouting shrubs).[151] The same study observed positive effects on the regenerated wood and negative effects on the proliferation of resprouters if stem-only harvesting was carried out leaving logging debris scattered in the logging strip. The **Aleppo pine** always has a high proportion of serotinous cones, whereas this cone proportion for the maritime pine varies between geographical zones and even between stands.[158]

Some studies have noted that high fire severity in the soil facilitates **maritime pine** regeneration and leads to higher density,[160] while others have indicated totally the opposite.[158] In certain cases, the severity of the fire has negatively affected regenerated pine density, but has had a positive impact on its survival 10 years after fire.[19] Fire severity does not influence the density of **Aleppo pine** saplings, but in cases of high fire severity, mortality among regenerated Aleppo pines was less, while growth was greater, compared to low intensity fires.[112] If regeneration is scarce (if the autumn after fire is dry), or there is a new fire before the cones have been formed, the area can easily be transformed into grass or scrubland, or a re-

sprouter wood. Nonetheless, in mixed clumps of Aleppo pine and holm or deciduous oak, if aleppo pine regeneration is good, this species rapidly colonises the area and resprouters are confined to the understory.[4]

In burned **Aleppo pine** forests in Sierra Nevada (Andalusia), regardless of whether whole-tree harvesting was employed in the logging process or whether all the remains were shredded and scattered, negative effects continued to be observed compared to non-intervention. Two years after logging, satellite images showed that vegetation in unlogged areas was 10% greener and soil surface temperature was 1°C lower in spring and summer. However, no differences were found between the two logging modalities.[167] Similarly, in **maritime pine** stands in the centre of Spain (Castile-La Mancha), the presence of snags significantly favoured the diameter and height of saplings 10 years after germination. The density of regenerated pine saplings was higher in the lower part of slopes and in places with greater leaf litter thickness after fire.[19] Even though only trees with little or no use for commercial logging are retained, wood retention, together with delayed salvage logging also increases the survival of new saplings. Finally, saplings that grow in the shade of shrubs have less biomass, but are more elongated.[152]

1.2 Non-serotinous pines

The adult plants of these pine species are resistant to ground fires, even intense ones, thanks to their thick bark and the discontinuity between understory and canopy vegetation. However, their survival does not necessarily lead to abundant regeneration. On the contrary, after a canopy fire these species lack the mechanisms to counteract the effects of the fire, and when they die their regeneration is compromised.[123] Thus, with little chance of the same species regenerating, salvage logging will not damage pine saplings. But if these species are restored by planting, the plant community will undergo a transformation towards grassland, shrubland, or deciduous and/or holm oak groves (when the latter are found in the stand).[123]

Black pine and **red pine** seeds are dispersed from March to June. Therefore, the pine cones that burn in summer fires are already empty and cannot release seeds after fire, and pine seeds fallen in spring have already germinated (end of spring) and die in the fire. The few ungerminated pine seeds on the ground cannot withstand fire temperatures.[123]

Stone pine cones do not open until autumn and some, but only a few, pine seeds can survive summer fires. Pine nuts are subject to great predation, and new shoots have a high mortality rate and do not lead to mass tree replacement.[123]

This means that, in general, salvage logging should be carried out in these stands 3 to 6 months after the fire, followed by planting or sowing for 3 years after fire if the aim is to regenerate the same species.[123]

The regeneration of non-serotinous pines is only possible using trees that have survived the fire in patches of unburned vegetation (between 10 and 15% of the area affected by fire in large fires in the centre of Catalonia [131]), such as isolated trees or on the edges of unburned stands. Nonetheless, pine seed dispersal distance is short (15 to 20 m in the case of Stone pine and less than 50 m in the case of the other two species) and the seeds are subject to high predation. In general, when plant cover following the fire is weak, pine nut predation is less likely. Regeneration is possible after a short period of time, when seed predation and plant cover are still weak after fire, but only in a strip of a few hundred feet next to unburned trees.[123]

If the **stand is a mixture of black pine and Aleppo pine** (or a black pine stand is adjacent to an Aleppo pine stand), post-fire regeneration may be sufficient to create a stand of Aleppo pine only. In this case, the stand can be treated as for Aleppo pine. If the stand is a mixture of **black pine**, **red pine** or **Stone pine** together with **holm** or **deciduous oak** or **cork oak**, it can be converted to an oak stand thanks to the sprouts produced by these species, with the adult pine trees that have been able to survive the fire (if it is not too intense) as secondary species. In the absence of resprouters or Aleppo pine, the stand can be converted to grassland or scrubland.[5,6,57]

1.3 Holm and deciduous oaks (except cork oaks)

Holm and common oak are very resilient to fire as they can resprout from basal buds on the stump, root crown and roots. On average, 85% of burned oaks in Catalonia (with the mortality of the aerial portion) resprout from the stump.[40] This capacity to resprout facilitates plant cover recovery, which in turn reduces the risk of erosion, favours nutrient retention and provides refuge for the fauna.[41] Resprouting vigour is greater and more abundant in adult specimens, since they have more basal buds and greater reserves. With age, the number of sprouts diminish and they are not so long.[39] Resprouting capacity decreases considerably after a second fire event, if this occurs within 5 years of the first fire.[39,40] In low quality forests, **holm oak** sprouts grow better than **common oak** sprouts; in high quality forests, the reverse occurs.[41]

Depending on the fire regime, resprouting is low when the fire is very severe. High fire frequency increases mortality and decreases resprouting vigour (especially if the period between fires is less than 5 years) due to the progressive destruction and depletion of the bud bank and stored resources.[39] End-of-season fires (late summer) are worse than those at the beginning of the season, since resprouting is less vigorous in late summer due to nutrient distribution in the tree. Since the summer dry season is expected to extend into autumn as a result of climate change, there is a risk that resprouting after a summer fire will be weak.[39]

After fire, provided there is moderate tree density, planting will not be necessary and plant cover will recover quickly, mainly with the same species. Thus, stands of 400 to 600 oaks/ha (mother trees) generate continuous cover within 20-25 years after fire.[39] However, **holm oak groves** can also be transformed after fire into Aleppo pine forests (with or without holm oak), cork woods (with or without holm oak), and grassland.[40]

1.4 Cork oaks

The cork oak is the only Mediterranean *Quercus* species that has epicormic buds on its branches (as well as on the stem, stump and roots),[162] which are located at a great height. When the bark is thick enough, these buds can survive the heat of a fire and allow rapid resprouting of the tree from the stem and branches. It is, therefore, one of the best adapted species to withstand recurrent fires. Its survival is high and tree cover regeneration after fire is fast.[23]

The location of sprouts varies depending on **fire severity**:

- Low intensity (surface fire without scrub): the trees have some charred leaves in the lower part; sprouts only appear on the branches.
- Moderate intensity (Surface fire with low scrub): trees are blackened or without leaves, but nor charred; sprouts appear on branches and stump.
- High intensity (bushfire that spreads to the canopy): trees may be charred at a depth of 1 to 2 cm; sprouts only appear on the stump.
- Very high intensity (canopy and bush fire): the tree dies.

Vulnerability to fire decreases as the thickness of the cork increases, up to 4 cm, and if 8-10 mm of cork has not been consumed after fire, it is unlikely that the "mother layer" will have suffered damage .[162] For the same thickness of bark and a normal girth, cork-stripped oaks are less resistant to fire than oaks whose bark has never been stripped. The most vulnerable are those that have just been stripped. They regain resistance and maximum protection when the bark is 3 or 4 cm thick again. However, with these dimensions the cork is stripped again (every 9 to 15 years), so in practice, the risk of damage to living tissues (cambium and phloem) is permanent. [23]

Depending on fire severity and cork thickness, several cases exist where it is necessary to cut a few stumps or the whole tree[162] (TABLE 7).

In addition to stump sprouting, the Eurasian jay scatters the acorn before the soil is covered with shrubs, favouring the growth of saplings in post-fire situations. [23]

TABLE 7. Assessment of fire damage and management recommendations for cork oaks.

Affected cork-stripped area [a]	Proportion of scorched canopy	Type of fire	Fire intensity	Time elapsed since last cork-stripping	Aerial tree mortality	Coppiced trees for stump sprout regeneration [b]
20-40%	50-100%	Old scrub, some dry combustible material under trees	Medium	< 6 years	Medium (30-60%)	Some very damaged trees can be logged for regeneration
> 40%	100%	Abundant scrub or debris under trees	High	> 6 years	Medium to low, depending on size and health of tree (0-60%)	Some trees can be logged for regeneration
> 40%	100%	Abundant scrub or debris under trees	High	< 6 years	High or very high mortality (> 60%)	Cut the tree. Regeneration from the stump and, if necessary, reforestation

[a] Burned proportion of log surface where last cork was stripped.
[b] In all other conditions, all less severe, it is advisable to preserve all the cork oaks to continue cork production.
Source: adapted fromVericat, P., Beltrán, M., Piqué, M. & Cervera, T. 2013. Models de gestió per als boscos de surera (*Quercus suber* L.). Producció de suro i prevenció d'incendis forestals. 1a ed., Orientacions de gestió forestal sostenible per a Catalunya (ORGEST), Centre de la Propietat Forestal. Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural. Generalitat de Catalunya.

1.5 Understory vegetation

Recovery of grass and bush cover after fire reduces erosion (see file "2. Reduction of soil erosion") and nutrient loss, protects the humic complex and soil structure (see file "3. Preservation of soil fertility"), recovers the necessary conditions for wildlife (see files "4. Conservation of invertebrate fauna" and "5. Conservation of vertebrate fauna") and speeds up the return of ecosystem services.[158] In burned stands where salvage logging is practised, these objectives should be carried out to complement tree cover recovery. For example, in Aleppo and maritime pine woods in the Mediterranean basin, stem-only harvesting and manual cutting has been shown to slow down plant cover regeneration, negatively affecting vegetation cover and species richness. Differences between burned and unharvested areas are greater in the first 3 or 4 years after fire, but these differences become less pronounced 9 years after fire.[9]

After fire, vegetation cover and herbaceous and shrub species richness are higher in calcareous than loamy soils. They are also higher on north-facing than on south-facing slopes. **Resprouting species**, such as the Kermes oak (*Quercus coccifera*) and Mediterranean false brome (*Brachypodium retusum*), reach high cover shortly after fire (less than 10 months) and this plant cover does not increase significantly over the following months. In contrast, the increase in **germinating plant** cover, such as gorse (*Ulex parviflorus*), is slower and more gradual, and germinating plants are more abundant after fire in the absence of resprouters (for example, in abandoned fields). Leguminous plants are usually plentiful after fire as they can fix nitrogen and live in environments where this element has been lost by volatilisation mainly because of the fire.[111]

One particular case are small woods dominated by the **strawberry tree** (*Arbutus unedo*), most of which are in Aleppo pine stands that have undergone successive fires. After fire, the strawberry tree sprouts vigorously, its growth stalls and both vertical and horizontal fuel continuity can be maintained for a long time. In Catalonia, it has been found that a selection of post-fire living stumps promotes greater shoot growth 3 years later, specifically 48% more in length and 60% more in girth. The more intense stump selection is, the more new sprouts (stools) grow the following year. On the other hand, clearing the stand does not affect either the growth or the number of new shoots. Finally, the selection of strawberry tree stumps guarantees the quantity of fruit and improves its quality, and does not alter the structure or composition of ant communities.[121]

1.6 Conversion of tree-covered areas towards open habitats

Since the beginning of the 20th century, the rural exodus from less productive land in Europe and the replacement of wood and charcoal for fossil fuels have led to an increase in wooded areas at the expense of farmland and pastures. Afforestation and agricultural and livestock intensification in fertile plains pose a threat to many open-habitat species, and certain plant, vertebrate and invertebrate species have decreased. Some of these species, endemic to the Mediterranean basin, or whose area of distribution is restricted to Europe, are currently endangered. [124,125] Others have an interest as hunting species. On the other hand, the greater abundance of open habitats favours the presence of a contingent of pollinators (mostly arthropods) that are less plentiful or absent in closed habitats. In regions with small areas of open habitats, the conversion of burned wooded areas (with little interest in terms of production and preservation) into open habitats (such as grassland or scrublands) can be an opportunity to recover them. [129,134]

Habitat conversion depends to a large extent on pre-fire vegetation. In the case of tree masses, conversion can be easier or more difficult depending on the post-fire strategy of the tree species in the stands. If there is an abundance of **sprouting species** (mainly of the genus *Quercus*), conversion to an an open habitat will be very difficult.[40] Similarly, serotinous pine woods (**Aleppo and maritime pine**) tend to present abundant post-fire regeneration, except in two cases: the occurrence of a second fire that burns the stand before it reaches the pole stage; that is, before the pine produces cones,[4] and pine stands with a weak proportion of serotinous pine cones.[158] In both cases, the stands can be converted to grasslands provided there are no resprouters. If pine regeneration is abundant, the thicket stage or the pole stage can be transformed by prescribed burning before the pines produce cones (around 15 years in the case of the Aleppo pine and 10 years in the case of maritime pine).

The woods that can be converted to grass or scrubland most easily are pure non-serotinous pine stands (black pine, Scots pine and stone pine) as their seeds have little capacity for dispersal or survival after fire.[5,6,57] In **stone pine** stands, due to their thick bark and the discontinuity between the ground and the crown, stone pines are commonly kept as secondary species in wood or scrubland after fire, thanks to the adult specimens that have survived and the number of seedlings that can thrive. If this pine is accompanied by resprouters, the stand will be replaced by a mixed wood.[57] However, in the absence of resprouters and with sufficiently high mortality, the stand can be redirected towards an open stone pine tree mass with an understory rich in typically Mediterranean shrubs (these stands are conducive to the production of pine cones and honey).[118] Goat and sheep grazing or low intensity controlled burns can help maintain this forest typology.

Black and **Scots pine** have higher mortality in severe fires and less regenerating capacity than the stone pine. Initially, mixed woods with resprouters in the understory tend to be replaced by pure tree masses: holm or deciduous oak. Pure tree masses with high mortality tend to be replaced by grasslands, with or without shrubs.[5,6] These can be kept as open environments by grazing. In holm and deciduous oak groves, clearing and selective thinning (leaving up to between 400 and 1.000 trees/ha and a fraction of canopy cover of less than 60%), converting them to sparsely wooded pasture for grazing, promoting an increase in the herbaceous layer and stimulating the production of tender shoots for pasture.[40] Red pine stands, where the trees have survived the fire, can also be converted to pasture by preserving between 350 and 650 trees/ha. Conversion to pasture can also be applied in pure stands or mixed stands of Scots pine with common oak. Management of the latter tends to favour oak over pine.[6]

The conversion of wooded areas to open habitats in the Areas for the Promotion of Forest Management (APFM) is of special interest as the low fuel load prevents large forest fires from spreading in these key locations. The actions proposed in this section seek to obtain this conversion without either clearing the vegetation or ploughing in the entire area to be converted. This conversion is also proposed with the aim of preserving open-habitat plant and animal species and extensively exploiting non-timber forest products (grazing, beekeeping, pine nut production, etc.).

2. REDUCTION OF SOIL EROSION

Objective: to reduce the risk of erosion caused by forestry work

2.0 General conditions

Soil erosion is the loss of solid materials from soil surface horizons by ablation caused by rainfall, gravity or the action of the wind.[31] After fire, the main cause of erosion is precipitation (or water erosion). In a burned area erosion can manifest itself in different ways[1]:

- Sheet erosion: this is superficial erosion produced by a flow of water which drains diffusely or in the mantle and where the particles it consists of move along flat, straight and parallel trajectories in relation to the flow axis. Although surface runoff carries away the ash deposited on the ground, this process is not considered to be sheet erosion since ash does not form part of the soil.
- Erosion in rills and gullies: these are temporary drainage channels on slopes devoid of vegetation and with rocky subsoil. Rills are less than 1 m wide and deep, while gullies range between 1 and 10 m in width and depth.
- *Badlands*: this landscape is typical of certain sub-desert areas characterised by the formation of gullies on slopes and narrow interfluves that form a dense network in clayey or loamy substrates..
- Wind erosion: this is superficial erosion caused by the action of the wind. Although the wind carries away the ash deposited on the ground, this process is not considered wind erosion since the ash does not form part of the soil.
- Mass movement: this is the displacement of materials towards the bottom of the slope as a result of the force of gravity, forming a body with certain cohesion due to the presence of water, ice or air in its composition.
- Wall collapse in agricultural terraces.

The capacity of the soil to recover after degradation caused by fire depends on fire conditions, ash properties, topography, post-fire weather conditions, vegetation recovery and environmental management.[50] Soil erosion after fire in Mediterranean forests is not normally critical for the environment.[102] Several studies have observed that during the first year after fire, in many cases soil erosion amounts to less than 1 ton per hectare, and in most cases, less than 10 tons per hectare (or approximately 0.07 and 0.7 mm of soil, respectively), although up to 80 tons per hectare can be lost during the first three years in severe fires on fragile soils.[43] These figures, mainly related to fire severity and rainfall intensity during the first year after fire, are similar or even lower than those of other disturbed lands (such as farmlands) or other environments with little vegetation (such as pastures or moors). Erosion diminishes considerably from the second year after fire and returns to its usual levels after 3 to 10 years.[144] As a general rule, risk of post-fire erosion is weak if the slope is less than 20%. In steeper slopes, the risk is only high when the surface fraction of the burned land covered by leaves from the charred crown is below 66%.[159]

Factors explaining the **weak erosion susceptibility of Mediterranean soils** include its high rock content and human-caused alterations over centuries that have resulted in the loss of most of the fine particles. On the other hand, not all soils are equally prone to erosion. The composition of the parent rock influences particle cohesion. For example, sandy soils formed from sandstone and soils developed on Keuper Marl and clay are more sensitive to erosion caused by post-fire logging[9] than limestone soils.[158] In fact, the erosion effect of salvage logging with stem-only harvesting and manual cutting in Aleppo pine and maritime pine forests in the Mediterranean basin do not seem to be linked to the basal area or to the density of extracted trees, but rather to the low cohesion of soil particles.[9] This cohesion depends to a large extent on the clay-humic complex, which is important in absorbing the impact of raindrops.

A specific period during which the soil is more sensitive after fire cannot be established, but it is known that erosion depends to a great extent on torrential rain episodes, type of fire (canopy or ground), fire severity (by leaf cover that might have been preserved), and fire recurrence,[144] and on vegetation cover restoration, especially shrub and grass.[55] Before vegetation is regenerated it is ash that protects the soil from erosion and facilitates water infiltration, except in the case of thin layers (< 1 cm) of very fine ash (created by high combustion temperatures), which can clog soil pores and facilitate runoff. However, thicker layers of ash (2-5 cm) will increase its water storage capacity, delaying and thereby reducing runoff to the extent that there is no surface flow, regardless of any clogging in underlying soil pores.[13]

The conditions that make Mediterranean vegetation communities resilient to fire can be disturbed by salvage logging. This forestry work increases soil compaction, density and fragility, as well as runoff, which is always higher than that of unlogged areas, even if wood is cleared using aerial systems (instead of being hauled), and track traffic is reduced and the tracks covered with logging debris. In fact, the characteristics of the soil itself, such as porosity and surface roughness, have a great impact on runoff. Only a smaller production of sediments is observed if clearing is done completely by log suspension, a method that alters soil less than hauling or half-dragging the logs. A year after logging, sediment production is similar to that of unlogged areas.[86,168]

Another source of erosion after fire are burned trees that instead of breaking at the trunk are knocked down and uprooted by the action of the wind. This situation can be serious in certain substrate conditions, fire severity and wind exposure and could be avoided by salvage logging: the initial harvesting of burned trees would prevent holes opening up where soil mineral is exposed to erosion. However, the magnitude of this source of erosion has not been measured and the conditions in which trees are uprooted by wind instead of breaking are not fully known. Whatever the situation may be, if cutting work is planned, the good practice recommendations should be taken into account, especially in severely burned areas. The state of the soil must also be evaluaed to consider erosion control procedures (see file "7.2 Erosion control procedures").

The application of a protective mulch covering, composed of logging debris and scattered over the logging strip, is the most effective treatment to reduce erosion.[46] In Galicia, the application of a shredded cereal straw mulch (1.5 or 2 tons per hectare) from a helicopter has proven to be a fast, feasible and effective method , although it has its limitations owing to the action of the wind, the sloping terrain, the cost and the risk of introducing allogeneic species. Mulch application from land vehicles has also been proven effective, as well as mulch based on shredded bark. In contrast, wood chip mulch is only effective if applied in large quantities, which increases costs.[43,44,159] TABLE 8 shows the characteristics of potentially protective mulch coverings.

TABLE 8. Characteristics of mulch for erosion control.

Type of mulch covering	Erosion reduction (average and interval)	Advantages	Inconveniences
Forest debris in eucalyptus plantations	96% (applying 8 tons/ha) 86% (applying 2.6 tons/ha)	Naturally present Soil loss is limited to less than1 ton/ha/year	Branches must be chopped and crushed to increase contact with the soil
Forest debris (bark, leaf litter and chopped branches)	90% (80%-95%)	Naturally present	Branches must be chopped and crushed to increase contact with the soil
Straw	80% (65%-95%)	Effective with light applications (up to 2 t/ha/year)	Poor durability
Hydro-mulch	60% (10% – 95%)	Permits planting at the same time	High cost
Wood chip	30 % (5% – 50%)	Long-term protection	Heavier applications (13 t/ha/year)

Sources: for eucalyptus plantations: J. J., Silva, F. C., Vieira, D. C. S., González-Pelayo, O., Campos, I., Vieira, A. M. D., Valente, S. & Prats, S. A. 2018. The effectiveness of two contrasting mulch application rates to reduce post-fire erosion in a Portuguese eucalypt plantation. *CATENA* 169: 21-30; the rest of the table has been adapted from Ferreira, A. J. D., Alegre, S. P., Coelho, C. O. A., Shakesby, R. A., Páscoa, F. M., Ferreira, C. S. S., Keizer, J. J. & Ritsema, C. 2015. Strategies to prevent forest fires and techniques to reverse degradation processes in burned areas. *CATENA* 128: 224-237.

3. PRESERVATION OF SOIL FERTILITY

Objective: to preserve soil fertility after fire

3.0 General conditions

The time just after fire is when the soil is most susceptible to erosion and nutrient loss. Preserving soil nutrients is key to maintaining productivity. Ash (mineralised nutrients) and organic material (nutrients for mineralizing) that remain after fire are essential for this preservation,[87,114] since the impact of fire on the nutrients available in Mediterranean soils is felt up to 18 years after fire. The most affected nutrients are the amount of total carbon, organic matter, extractable carbon and magnesium, and also the total amount of nitrogen. This nutrient loss can be attributed to the elimination of burned vegetation as a result of salvage logging, erosion, leaching and the burning of vegetation by the fire. Obviously, the more severe the fire is, the greater the nutrient loss.[52]

With the **mineralisation** of the biomass caused by combustion (e.g. nitrification) and its dispersal in the soil, the nutrients become soluble and are easily absorbed by plants. This has a fertilizing effect on post-fire vegetation and can accelerate germination and understory regeneration. This effect depends on fire intensity. Thus, in the Mediterranean basin, low or moderate intensity forest fires can increase fertility without having a marked impact on erosion or runoff.[72] This increase in fertility can, however, be counterbalanced by an increase in stress on the environment caused by the fire.[152]

The chemical composition of **ash** depends on the plant species and the degree of combustion. Some important chemical components for the ecosystem, such as nitrogen and carbon, begin to volatilise at around 200°C, and disappear completely at 500-550°C. Thus, ashes produced in high intensity fires are very poor in these fundamental elements for ecosystem recovery. In addition, their granulometry is finer and they are, therefore, more mobile. Other important elements for plants such as calcium, magnesium, sodium and potassium are volatilised at very high temperatures (>800 °C), which rarely occur in forest fires. These nutrients can be exported and lost outside the burned area through smoke, ashes in convection or erosion. Those that remain in the soil and fertilise it will depend on the type of soil, its cation-exchange capacity and on climate conditions. The most desirable option is for the ash to remain in the soil, especially when most of the plant mass has been affected by a severe fire.[114]

Due to the mobility of ash, **burned biomass** plays a key role in nutrient preservation. There is a greater concentration of nutrients in leaves and twigs. However, where most nutrients are located is in the trunk and branches (two-thirds of post-fire biomass, the other third being below-ground biomass) due to their greater mass.[88] While leaves and twigs are burned and transformed into ash, the trunk and branches are left and slowly decompose, releasing nutrients that allow the soil to remain fertile after fire. The action of decomposition is carried out by saproxylic organisms, so we recommend that you also check Section "4.2 Saproxylic invertebrates and control of wood-boring insects". These nutrients pass into the deposit of organic matter in the form of humus, which will be responsible for rationing them and supplying them in the post-fire recovery phases. In the absence of humus, nutrient retention is impossible. Thus, fertility not only depends on the presence of mineralised nutrients, but also requires the clay-humic complex and humidity to retain and mobilise them. A slow-burning, underground fire practically destroys this complex and destructures the soil.

Organic matter, nitrogen and carbon in organic compounds, and inorganic phosphorus, among other nutrients, are incorporated into the soil from the dead wood. These contributions equal[88] or exceed[87] potential contributions to the ecosystem from atmospheric deposition or nitrogen fixation by the roots of legumes. The effects are long-lasting since the nutrients are released slowly.[87] In the case of pines, the burned trunks with greater girth decompose more quickly than those with smaller ones. The speed in heterogeneous decomposition extends the period during which the burned wood supplies nutrients to the ecosystem, and although decomposition speed is slower in Mediterranean climate conditions (due to the lack of available humidity) than in other forest biomes, this process is fast enough to be a significant support for the nutrient cycle.[97] When wood decomposes, it allows an increase in the soil's microbial mass and respiration rate, facilitates microbial processes[89] and diminishes soil density, all of which favour water infiltration and root penetration.[56] After fire, and depending on its characteristics, oxidative decomposition processes accelerate, which entail the rapid mineralisation of the small organic fraction still left in the soil. Burned plant debris helps regulate this process. In Mediterranean ecosystems, salvage logging can have a detrimental effect on soil fertility, exporting a large part of the nutrients in the environment,[87] harming microbial mineralisation, disturbing the biogeochemical and physical functioning of the soil and delaying the ecosystem's capacity to restore its function as a carbon sink.[88,143] More specifically, salvage logging increases soil density, reduces aggregate stability, field capacity, and the amounts of organic matter and nitrogen. Microbial communities affected by fire recover sooner in the absence of logging.[53]

Studies on the impacts on soil caused by salvage logging mainly focus on erosion;

very few have explored the impact on soil chemistry and its nutrients, and even fewer have compared different harvesting systems.[80] A recent study carried out on a fire in the *Serralada Litoral* (Catalan Coastal Range) (Catalonia), measured different soil nutrients and chemical parameters (in a 0-5cm soil layer) 2 and 10 months after fire, according to three treatments: manual logging and stem-only harvesting; manual logging without harvesting, and no logging. In all cases, the pH, calcium, magnesium and potassium decreased over time while the C/N ratio increased. Curiously, the harvested plots presented greater aggregate stability, more total nitrogen and more organic matter in the soil than logged plots without harvesting, and the amount of inorganic carbon was greater in the latter than in the plot where no logging was carried out. According to these results, salvage logging, with or without harvesting, does not significantly affect soil chemistry and its nutrients.[51] The lack of other studies makes it difficult to draw general conclusions from this experiment, which moreover, did not include whole-tree harvesting where the export of burned biomass is higher.

3.1 Eucalyptus plantations

In eucalyptus plantations in humid Mediterranean regions, the nutrient with the largest losses (in terms of relative value) is phosphorus. The loss of this nutrient will lead to a decrease in productivity in successive rotations. Since eucalyptus roots descend as far as the regolith, where the weathering of the parent rock occurs, the loss of phosphorous will be felt after the last resprouting when the stumps are removed and the new eucalyptus hardwood cuttings, whose roots are not deep enough to reach the regolith, are planted.[154]

Eucalyptus debris (mainly bark) is a source of calcium and magnesium. These elements are easily dissolved in runoff water.[155]

4. CONSERVATION OF INVERTEBRATE FAUNA

Objective: to conserve the biodiversity of invertebrate organisms after fire

4.1 Soil and litter fauna

Epigeal invertebrates (which live on the soil surface) and **hypogeal** invertebrates (that live under its surface and in the leaf litter layer) play an important role in forest fertility, health and productivity since they shred plant material, help mineralise the nutrients for plants, contribute to soil formation and structure, and are part of the trophic chain.[106] In addition, they have mutualistic interactions with many plant species, such as the pollination of flowers and seed dispersal. Forest fires can dramatically affect these communities and reduce the abundance and diversity of soil fauna. Thus, by converting a wooded environment into an open habitat, the impact of fire on Hymenoptera and Diptera is greater than that caused by different harvesting systems (stem-only harvesting, subsoiling with plantation, or no harvesting). Yet, the impact of these tasks is not homogenous.[95] Fires in which the soil is most severely affected (assessed according to the depth at which the soil has been burned) have a more detrimental effect on hypogeal fauna.[85] Therefore, you should give priority to the recommendations on minimizing the impact on soil invertebrate fauna in places that have been severely burned.[54]

The recovery of these animals after fire depends not only on their **immigration from burned areas**, but also on **local survival in fire refugia**, especially in places where the fire was less severe (patches of unburned vegetation and also litter patches, where there has been a canopy fire but the understory has not been burned, or only slightly burned). In some cases, these effects can be felt in the long term, up to more than 7 years after the fire,[171] whereas under certain conditions, soil arthropod communities can recover their complexity after 2 to 5 years after salvage logging.[103] The species that depend more on humus, litter and closed habitats are the most sensitive, while those that live above the plant cover or tolerate arid conditions and open habitats are the most abundant in the early stages of recolonisation,[14,139] as is the case of certain species of ants,[95] Coleoptera[69] and snails.[139]

Soil surface invertebrates (**epigeal**) are more vulnerable to fire than hypogeal invertebrates. But as they are more mobile, recolonisation of the burned area is determined more by habitat suitability than by isolation.[14,95,171] For some, such as certain macroarthropods or gastropods, this suitability is directly related to the amount of organic matter in or near the soil (for example, burned branches left scattered on the ground),[14,171] while for others, such as certain hymenoptera and coleoptera, heterogeneous habitats (such as those produced by low or moderate intensity fires, or even by partial salvage logging) can attract more families and increase diversity.[3,69,95] Nonetheless, the number of individuals may be similar between unburned forests and burned forests with stem-only logging with or without subsequent pine plantation, or burned forests without harvesting.[95] In other cases, the biomass of soil arthropods is similar between stands with post-fire salvage logging and logged areas around living pine stands. However, in the second case, there is less density of individuals and these are larger in size.[59]

Recolonisation, especially by groups of animals that are not very mobile is also facilitated by unburned corridors that connect litter patches to the unburned forest. In this way, litter patches surrounded by burned soil give shelter to a lower abundance of epigeal invertebrates, while the patches connected to unburned areas have a greater abundance.[171] However, for the less mobile epigeal invertebrates, such as gastropods, recolonisation from the unburned forest (even though it is only a few metres away) may be very weak and the most frequent recolonisation method is from small populations of fire survivors.[139]

Soil invertebrates (**hypogea**) recover mainly by local survival in deeper soil horizons, which appear to be independent of the presence of unburned corridors.[171] Their survival depends on the type of fire. Subsoil fires will have a greater impact than understory fires, and the latter more than canopy fires. The impact of fire on invertebrates that feed on roots, such as cicadas, can be delayed by one year. This is the time it takes for the roots of resprouting plants to degrade. Salvage logging does not affect root degradation. By not dying, the roots of resprouting plants offer continuous support for these organisms.[120]

Generally, survival of soil animals and their recovery depend to a large extent on the quality and quantity of organic matter in the soil.[171]

4.2 Saproxylic invertebrates and control of wood-boring insects

Saproxylic invertebrates are one of the most endangered functional groups in European forests and can benefit from the generation of dead wood produced by fires. Deadwood-eating Coleoptera (beetles) and their predators are some of the first organisms to colonise recently burned forests. There are saproxylic Coleoptera species and other saproxylic organisms specialised in detecting burned wood; pyrophiles, such as *Melanophila acuminata* (Coleoptera, Buprestidae,) or *Acanthocnemus nigricans* (Coleoptera, Acanthocnemidae). These species play a key role as pioneers in the colonisation of burned trees, initiating different decomposition processes. Accordingly, it should be taken into account that the community involved in the decomposition of wood tissues in trees burned by fire differs from the one involved in decomposing wood that is dead due to other circumstances (Eduard Piera, pers. com.).

The main service provided by saproxylic invertebrates is the decomposition of organic matter so it can be reincorporated into the nutrient cycle. They influence and regulate decomposition through enzymatic digestion, alteration of the substrate, biotic interactions with other decomposers and nitrogen fertilisation. Despite being basic aspects of ecosystem functioning, little is known about their interaction with fires and salvage logging (Eduard Piera, pers. com.). The excreta of larvae fed on dead wood enriches the soil in organic nitrogen and carbon, and increases microbial respiration in soil minerals up to three times more than in stands where salvage logging has been carried out. The excreta can cover a good portion of the forest soil and facilitate plant recolonisation of the burned area.[28] Decomposing organisms are more abundant in burned trees with a greater girth (especially larvae of larger xylophagus insects) and as a result, this wood decomposes more quickly than in trees of a smaller diameter.[97]

Salvage logging negatively affects saproxylic invertebrates. In logged stands, species richness is lower than in unlogged burned forests, mature forests and even in freshly logged mature forests. Thus, the impacts of fire are synergic and greater than the combined effects of fire and logging taken individually. These important differences in species composition are due to the sharp decrease in the quantity and quality of large-size dead wood in burned and logged stands.[29] Some Cerambycide species are even completely absent from burned forests where salvage logging has taken place, although adults may be relatively abundant in burned stands or in logged unburned stands. This is because larvae laid in tree trunks after fire are exported out of the forest as a result of logging.[28] Another example is the stag beetle *Lucanus cervus* (Lucanidae). At present, highly decomposed oak stumps generated by a fire in Montserrat (Catalonia) in 1986 provide a habitat for this species as well as for another Iberian-Maghreb lucanid, *L. barbarossa*. Appropriate management is needed, therefore, if signs of colonisation of these species exist in the burned area to be managed (Eduard Piera, pers. com.).

Conequently, the logging of burned forests may have serious consequences for saproxylic invertebrates, especially pyrophiles, and for their ecological functions in post-fire forests.[29] Knowing that the amount of large-size wood is far lower in intensively-logged than natural forests (between 90 and 98% in some cases), a large number of saproxylic species may have disappeared from wood-harvested forests, a situation that is worsened by salvage logging.[147] For this reason, leaving or generating large-size dead wood in green forests may be beneficial for many forest processes, one of which is to facilitate colonisation if there is a nearby forest fire. Pre-fire landscape management should be taken into account (Eduard Piera, pers. com.).

Post-fire salvage logging has often been justified by alleging the risk of infestation of neighbouring living stands by insects that breed in the wood of trees weakened by fire (mainly Scolytidae). A distinction must be made between conifers, highly sensitive to attack by primary Scolytidae (Scolytinae, Curculionidae) under specific circumstances, and planifolia, less likely to develop such infestations. It is not true, therefore, that there will be major insect outbreaks, and hey are also unrelated to the ones that occur in Central European and boreo-alpine forests. Action should be taken on a case-by-case basis to see if leaving a certain volume of dead conifer wood influences the risk of pest infestation (Eduard Piera, pers. com.).

Only a minority of **wood-boring insects** are able to break through the barriers of a living tree, even a dying tree;[60] just some Scolytidae and very few others. Species of the Buprestidae, Cerambidae, Hymenoptera and Siricidae families, practically in their entirety, are only capable of living in dead trees, or in living trees with dead parts, and they are highly common in burned or old trees (Eduard Piera, pers. com.). Species of the genera *Tomicus* and *Ips* (of the Scolytidae sub-family) prefer dying pines or ones that are not severely burned, especially those that have a small girth and thin bark, those whose stem is charred at a greater height, and those located where the soil has been most severely affected by fire. They avoid healthy trees and completely burned trees with leaves consumed by fire.[9,138] Thus, the risk of burned wood left in the forest becoming a focus of infestation for neighbouring stands is minimum.[60] Wood-boring insects are only a threat to the survival of trees weakened by fire,[138] or to tree masses that have been weakened by recurring episodes of water stress, for example. In this case, felling the dying trees on the periphery is recommended.

5. CONSERVATION OF VERTEBRATE FAUNA

Objective: to conserve the biodiversity of vertebrate organisms after fire

5.0. General conditions: birds, mammals and herpetofauna

In the Mediterranean basin, the effects of fire are very variable and depend on factors such as the burned surface area, severity, frequency, initial state of the ecosystem, dispersal and the isolation of burned patches, and various abiotic conditions. In general, burned wooded areas harbour less rich and less abundant vertebrate populations.[21,63,84,134] These are composed of open habitat or ecotone species, such as the common rabbit (*Oryctolagus cuniculus*)[130] and the partridge (*Alectoris* spp. or *Perdix* spp.),[129] as opposed to forest stands with closed canopies that are home to populations of species that avoid open areas. Forest fires reduce the availability of habitats for animals in woodland environments and have a greater impact on specialist than generalist species (like omnivores).[140] This does not imply that the impact of fire is necessarily negative from the perspective of biodiversity conservation. Fire can create a heterogeneous landscape with open areas, critical for the maintenance of species specialised in open habitats, and unburned plots, which provide shelter for woodland and ecotone specialist species. In addition, the lower number of "short-term" species after fire is compensated by a greater diversity accumulated over time as the vegetation is regenerated. For example, meadow and grassland bird species, mainly present in the first and second year after fire, such as the wood lark (*Lullula arborea*) and the tawny pipit (*Anthus campestris*) are gradually replaced by shrub species, such as the warbler (*Sylvia* spp.) and the melodious warbler (*Hippolais polyglotta*), which appear from the second or third year onwards, depending on the shrub height they require.

From a management viewpoint, maintaining a landscape in the Mediterranean region with a mosaic of habitats with different fire histories is vital for the preservation of high vertebrate diversity.[65] In certain regions, hunting activities are restricted for a period of time after fire. This measure can help restore open-habitat animal populations.

The richness and abundance of closed-habitat mammal and bird communities diminish for at least the first 10 years after fire.[142] However, in the case of birds, the number of species may increase during the first years after fire thanks to the opening of the tree canopy (which attracts open-habitat species). In addition, the presence of standing dead trees (snags) allow certain birds to be retained (although as the snags fall these woodland species leave).[84] It can take up to 50 years before these communities are similar to those that existed before the fire.[142] It is therefore essential that post-fire harvesting is adapted to the fauna management objectives of the territory. In regions with a deficit of open habitats, with little anthropisation, fires can be an opportunity to create these open spaces. Later on, management can focus on maintaining a part of these open habitats for preserving the associated specialised fauna.

Recolonisation of the burned area can be done from outside the area or from individuals that have survived in the unburned patches. The importance of each of these strategies will depend on the animal species. In the case of terrestrial **mammals**, recolonisation by residual populations that have survived in the unburned patches is usually more significant than recolonisation from outside the burned area.[8] This demonstrates the importance of conserving these patches of unburned vegetation, which are essential focal points of recolonisation, and reducing the impact of activities that can break up burned territories, such as salvage logging, during the early stages of recolonisation (although these impacts may be felt later).[8]

Birds have a different behaviour due to the use they make of snags, and depending on whether they are open- or closed-habitat species. In Mediterranean pine and holm oak forests, fire modifies the composition of closed habitats less than might be expected. Inertia of the fauna (or loyalty to the site) can be observed after fire, resulting mainly from the persistence of snags, an effect that can last up to 3 or 4 years, but can quickly be suppressed if salvage logging is carried out. After the disturbance, several species, such as the short-toed treecreeper (*Certhia brachydactyla*), the great spotted woodpecker (*Dendrocopos major*), the long-tailed tit (*Aegithalos caudatus*), and the chickadee family (*Parus* spp.) make use of snags during winter and the breeding season to look for food, perch, nest and as surveillance posts. Cutting these snags causes a decrease in species richness and he number of individuals.[84] These biological legacies are important since, in the first stages of succession, the differences in avifauna are more influenced by habitat structure than by plant composition.[64]

In the first 3 years, above all, burned trees stand upright and therefore the woodland is slowly transformed into an open environment colonised by species specialised in open or shrub habitats.[84] Salvage logging accelerates this colonisation process,[64] which is determined by habitat proximity and by the fact that these bird species are adapted to living in a matrix where open and closed habitats coexist; two commonly-found conditions in the Mediterranean basin.[15,16,135] This means that there are often no differences in species richness between burned pine stands with or without salvage logging.[64]

The response of **reptiles** to fire depends more on habitat recovery conditions than on fire variables.[104] For example, in the short term species respond to the microhabitat they occupy. Species that live among rocks and are little affected by fire, have a positive response to fire. In contrast, reptiles that live in the understory have a negative response. Rainfall also influences habitat recovery; recovery is faster in areas with more rainfall. If pre-fire vegetation is a low-quality habitat for reptiles, such as densely-populated conifer plantations, plant cover removal by fire and subsequent salvage logging can increase the abundance of reptiles due to greater exposure of the soil to sunlight.[7]

Whatever the recolonisation strategy, the new colonisers will find themselves with a space with limited resources compared to before the fire.[8] It is therefore important to identify what attributes of the new habitat facilitate their survival, such as refugia for small mammals and reptiles, sunny spots for reptiles, or tree hollows for bird nesting and bat shelter.[7,70,81] It is essential that these attributes are maintained when salvage logging is carried out, since this favours a more heterogeneous habitat with greater biodiversity. For example, forest birds often continue to occupy unlogged burned areas, open-habitat species occupy logged areas, and shrubland species become established in areas where shrubs or the understory provide more cover.[134] Tree regeneration also influences recolonisation of wildlife habitats. For example, while post-fire oak saplings quickly develop branches and can soon be used by birds, pine saplings take years to acquire an important role for avifauna.[84] In contrast, after 3 or 4 years these same saplings provide good shelter for rabbits.

On the contrary, forest fires can be an opportunity to restore open habitats with a high degree of intactness in areas where these spaces are not abundant or where, despite being present, they have been greatly anthropised (such as agricultural areas and intensive pastureland).[129] Thus, at landscape level, fires can increase habitat heterogeneity and, as a result, vertebrate richness.[64]

6. POST-FIRE RISK REDUCTION

Objective: to reduce the causes that increase fire risk after salvage logging

6.0 General conditions

The fire regime in the Mediterranean basin is characterised by high recurrence.[110] Although fires occur mainly during climate conditions of prolonged drought and high temperatures, forest composition and structure greatly influence fire risk. **Dead wood**, due to its low humidity and density and the presence of cracks, catches fire more easily than living wood.[170] In the drier areas of the Mediterranean basin, burned dead wood can remain for 30 years or more, conserving its combustion capacity.[149] These observations are used to justify the practice of salvage logging: to reduce the amount of available fuel for a new fire, because if it occurs, it will be easier to control and exting uish.[68,109,115,127,149,167]

After fire, numerous woody remains are left unburned, mostly in the form of **standing dead trees (snags)**. As the understory is where most fires start and initially spread, snags are not considered to influence the fire hazard while they remain standing.[17,66] Over time, they are blown down by the wind and plant cover regenerates, two processes that accumulate surface fuel.[127,156] In general, snags with a larger girth remain standing longer, but the tallest ones are more susceptible to breaking.[127] In Aleppo pine forests in the centre of Catalonia, 80% of the pines were still standing 3 years after fire, but snag fall accelerated after the fourth year, and 6 years after fire only 25% of burned pines remained standing. In the case of holm oaks, wood decomposition and falling processes are slower.[84] In the pine forests of Sierra Nevada (Andalusia), pines were still standing the second winter after fire and not all of them had fallen until 5.5 years after fire.[96] Whether the snags are in clumps or scattered does not influence fall rates,[127] although scattered snags (when 90% of the trees have been felled in the salvage logging process) tend to fall more quickly, although the difference is not significant.[96] Burned pine trees with a smaller girth take longer to fall, but again, the difference is not significant. The altitudinal gradient has no influence whatsoever.[96]

According to fuel models, the parameter that exerts the greatest influence on the fire behaviour of dead wood is the **girth**: thinner tree girths (mainly branches) catch fire more easily, the flames spread more quickly and a greater proportion are consumed (this proportion is greater in soil residues in intense fires and in suspended residues in low-intensity fires). In contrast, snags with a larger girth (trunks with a diameter of over 20 cm) burn longer, but have very little influence on initial fire intensity and spread since they retain more humidity and have a smaller surface-to-volume ratio,[17,127] and their proportion of burned mass is lower.[157] When snags fall they continue to be suitable fuel. The parts that remain in contact with other fuels retain more humidity and therefore burn less readily, but they are in contact with other fuels (such as litter and understory vegetation), while the suspended parts are a better fuel source because they remain drier for longer, although they are further away from surface fuels.[157] Since the trunks usually end up in contact with the ground and the (suspended) branches, it is the latter that pose a greater risk for the spread of a possible future fire.[1] Burned wood is not a static fuel and it is known that in the case of pines (Scots pine, black pine and maritime pine), burned trunks with a greater girth decompose more quickly than thinner ones. While 5 cm-diameter trunks have barely lost any weight 10 years after fire, the thickest ones can easily have lost 30%, or even up to 60% of their weight.[97]

Salvage logging with whole-tree harvesting is the most effective method to reduce this fuel source.[127] The disadvantage of stem-only harvesting is that the branches and crown are left on the ground, immediately increasing the **amount of fine surface fuel**[36] (unless the branches are harvested later). The horizontal distribution of these branches, either left in piles or scattered, forming a continuous and homogeneous cover, will influence the spread of fire. Finally, leaving the area unharvested prevents immediate surface fuel contribution, but in the mid-term (from the third year after fire), there begins an accumulation of both trunks and branches that are still able to burn.[71,127]

Regeneration management carried out after fire can also have an influence on the risk of fire disturbance if it occurs again.[156] After salvage logging, despite the large amounts of dead wood collected during logging, coniferous plantations are susceptible to subsequent high-severity fires (although fire intensity may be low due to the small amount of fuel).[81] This is due to the plantation structure during the first years, when crowns are exposed to the wind and closer to herbaceous and heliophilous shrub flora that act as surface and ladder fuels, and are present thanks to the weak fraction of canopy cover. This fire risk is maintained whether the plantation has been cleared or not, and will not decrease until the fraction of canopy cover reaches percentage values of between 70% and 90% and the crowns are high enough to be separated from surface and ladder fuels.[11,149]

Therefore, taking temporal fuel dynamics into consideration, salvage logging alone cannot drastically reduce the risk of a subsequent fire. Fuel load reduction and its influence on fire risk requires the informed handling of future fuel accumulation, including not only that of the burned vegetation but also that of the regenerated tree mass. The benefits of post-fire fuel management in maintaining the resilience of the ecosystem have to be weighed against the negative effects that the removal of these biological legacies can have on the structures and functions of the ecosystem.[37]

7. PRESERVATION OF THE QUALITY OF RIVER AND RIVERBANK HABITATS

Objective: to reduce the impacts of fire and salvage logging on river and riverbank habitats

7.1 Riparian forests and water courses

Mediterranean ecosystems show rapid regeneration after fire, and river and riparian habitats are no exception. **Fire impacts** on water courses are due to increases in erosion and runoff from severely burned basins during storms, especially during the first heavy rains. The increase in water contributions, dissolved materials, nutrients, sediments, organic matter and ash to water courses is usually observed for a few months, or up to 4 years after fire. Populations of benthic algae, invertebrates, amphibians and fish decrease (or may temporarily disappear from some sections) as a result of flash floods after the fire.[165]

In general, both perennial and intermittent water courses recover their geomorphological and biotic characteristics without human intervention in only 1, 2 or 3 years after fire (in the case of fish, recovery is determined by the barriers that prevent their migration). This return to pre-fire conditions is associated with the restoration of the plant cover in the burned basin, which slows down sediment contribution and regulates runoff (decreasing flood peaks), and which generally occurs less than five years after fire. It is also linked to new torrential rains that in 4 or 5 months clear away the sediments and ash covering the water course and filled pools during the month after fire.[165]

Riparian forests cushion the impacts of fire on fluvial ecosystems since they retain the sediments that would otherwise reach water courses, forming fertile river plains; hence the importance of preserving them in proper conditions.[32,38,122,165,169] Riverbank forests are a transition zone between aquatic and terrestrial ecosystems, especially for amphibians, and they support great biodiversity.[27] In burned basins, where riparian forests have been preserved, aquatic invertebrate composition changes very little and resembles that of unburned basins.[165] Disturbances in riparian forests affect habitat availability in the water course and these effects are more intensely felt when the course in narrower.[32]

Riverbank forests can be used as fire breaks since they are less combustible due to the high humidity of plant tissues and lower temperatures than in adjacent forests.[38] Their effectiveness is directly proportional to their width, leaf moisture and relative air humidity. These characteristics decrease as we move away from the water course. However, large forest fires in the Mediterranean basin often occur in extreme drought and wind conditions, situations in which riparian forests can catch fire, although they are often only partially burned. When this happens, an increase in benthic algae occurs due to the increase in light in the water course; invertebrate communities become dominated by *r*-strategist species (species with a high birth rate, which neglect their offspring, and have a high mortality rate), and intermittent streams dry up more easily during summer because of greater evaporation. The regeneration of riparian forests depends less on the seed bank and is based more on the resprouting of the woody species that have survived the fire, or on the germination of annual plants from unburned areas, and is accelerated by the moisture and nutrient richness of the soil, recovering initial plant cover in 3 to 6 years. However, this process can be interrupted by floods following the fire, causing secondary mortality.[165] The presence of **dead wood in riparian forests** after fire is important to maintain the quality of these habitats. Most of the burned trunks are still standing immediately after the fire (from 57% to 83% 2 to 3 years after fire) and their roots contribute to the stability of riverbank slopes until they decompose. Fallen trees provide the river with dead wood, especially during the two years following a fire, even though the riparian forest may be narrow. In general, pine stands provide a greater volume to water courses than oak or holm oak stands.[165] This dead wood acts as a cover and habitat for riparian and aquatic organisms, an essential contribution after the fire has destroyed part or all of the canopies that provide shade for the river.[32] When floods occur, the repercussions of dead wood inside the riverbed are variable, depending on the depth and speed of the water, the dimensions of the water course and the number, size and location of core clusters of trunks and branches in relation to the current. Normally, these materials increase the roughness of the riverbed and raise the levels of water depth. A 20% to 40% occupation of the watercourse by accumulated dead wood generates a 10 to 20 cm rise in water depth. These effects, however, cannot be generalised since, in most cases, the geometry of the river channel adapts to the new conditions of roughness. Accumulations of dead wood can cause lateral overflows onto terraces and often generate disturbances that can lead to processes of riverbank erosion. Despite this, it also has interesting positive effects that must be taken into account in the rational management of riverbed maintenance; in particular, the regulation of overflows to prevent flooding in sections of interest; retention of sediments, floating elements and deposited materials, diversification of wildlife habitats, and the differentiation of the route of shallow waters in the water course according to specific objectives.[32,61]

The best **ecological restoration** of river and riverbank habitats is non-intervention, both in the riparian forest and in the rest of the unburned forest. After the 2003 fires in Sant Llorenç del Munt Natural Park, a multidisciplinary project was launched to accelerate the regeneration of the burned area. Mitigation measures included the construction of sediment sinks, riparian forest reforestation and the removal of dead trees. Although 4,000 native trees were planted as part of these efforts, while studies conducted up to 6 years after the fire revealed that no significant differences in regeneration could be found between the restored areas and the unmanaged burned areas. In addition, it was concluded that the construction of roads to remove dead trees after the fire had caused more soil erosion than the fire itself.[165]

7.2 Erosion control procedures

Erosion control devices are systems aimed at retaining sediments in the same burned area, thereby preventing soil loss, or in intermittent streams to mitigate the filling of downstream aquatic infrastructures, such as channels, dams or ports. When pines are available, log debris dams are an efficient, cost-effective method for retaining sand particles in intermittent tributaries before they reach the main channel. Despite the high cost of log erosion barriers, this is an interesting method because it retains the soil on the slopes. These two methods can be used together since they are complementary, and they both depend on the availability of straight pine logs. Finally, sediment capture ponds are the most effective method for trapping sediments with diverse granulometry. They are useful when there are no pine trees or logs straight enough to build dams or barriers.[49]

Installing these devices is expensive, so knowing in advance where there will be a higher risk of erosion just after fire is recommended. Risk modelling can be based on four variables: slope, pre-fire vegetation density, fire severity and soil erosivity. Once the areas with greater risk of erosion have been identified, actions that help the eroded soil particles reach the watercourse more easily should be prioritised, as should construction of the devices in the most feasible location. It is necessary therefore (1) to determine in which high risk erosion areas the eroded material can reach the main watercourse more easily; (2) to evaluate which soils have greater value in order to protect them; (3) to check the availability of pines for the construction of log erosion barriers or log debris dams, since straight logs can facilitate construction, and (4) to check site accessibility. Devices should be placed as soon as possible after fire as the first rains generate more erosion. They must be correctly installed to be effective, and of suitable dimensions to reduce costs given that these devices tend to be oversized.[48]

Log debris dams are placed every 25-30 m in intermittent stream beds. They should extend 3m beyond each side of the stream. They can be built with tree trunks or branches, but gaps between the logs must be avoided (by covering them with branches or twigs). Making them higher than necessary should also be avoided. The maximum thickness of sediments accumulated in Mediterranean conditions is 80 cm in most cases. They must be fixed firmly in place to prevent them from being swept away by floods. Eight days' work for 2 workers should be calculated to cover 500 m of the stream and construct 20 log debris dams. The maximum cost is €143/m^3 of trapped sediment for dams between 60 and 150 cm in height.[49]

Log erosion barriers should be positioned parallel to contour lines. They consist of two overlapping logs with no cracks, which must be as long as possible (a great height is unnecessary in Mediterranean conditions). The bottom log must be completely in contact with the ground, laying it in a trench. It is important to respect these instructions since rill erosion can otherwise be accentuated by rainfall concentration. The maximum cost is €250€/m³ of captured sediment.[49]

Sediment capture ponds serve to speed up the sediments transported by water. This is the most effective method since ponds from 30 to 260 m³ capture between 54% and 85% of sediments of all sizes. Nonetheless, they are too small to filter flood flows. While log erosion barriers and log debris dams capture mainly sand, sediment ponds act as a basin for grains of any granulometry. Consequently, the construction of sediment capture ponds may avoid installing log debris dams. The maximum cost is €217/m³ of sediment captured by a 180 m³ pond.[49]

Dead wood barriers following contour lines are not an effective method for reducing erosion. Due to the absence of a cross-sectional barrier in solid contact with the ground, they can only reduce the impact of raindrops on the soil surface they occupy, but they cannot decrease runoff. To maximise the anti-erosion effect of unwanted logging debris, or when erosion control devices cannot be built, the most effective way is to spread logging debris along the logging strip, chopping up the longest branches.[46]

FIGURE 3. Scots pine forest after stem-only harvesting. **Image:** R. Puig-Gironès.

RECOMMENDATION SELECTION TOOL

The purpose of the best practice recommendation selection tool for post-wildfire management is to guide the manager towards the relevant recommendations, based on the combination of several factors. The tool takes the form of **flow diagrams**. Based on these, a list of recommendations will be obtained that should be implemented to reduce the possible impacts of salvage logging on environmental elements, depending on available means and on four major objectives for the burned area.

The **four major objectives** are:

1. **forestry production** (wood and non-wood forest products) in the forest environment,
2. **biodiverity conservation** (mainly, but not exclusively, in protected natural areas, or in trust areas),
3. **creation of open habitats** (with or without pasture lands), and
4. **subsequent fire risk reduction**.

More than one of these objectives may coexist in the same burned area.

In forests where the main objective is **forestry production in the forest environment**, the possibility of employing all types of harvesting and clearing systems is considered, while aiming for minimum impact. When the objective is **biodiversity conservation**, the aim is to allow as little machine traffic as possible and to leave the maximum biomass in the logging strip. Hence, felling should be carried out manually, stem-only harvesting should be implemented, priority should be given to aerial clearance systems, and the option of not harvesting dead wood might be considered.

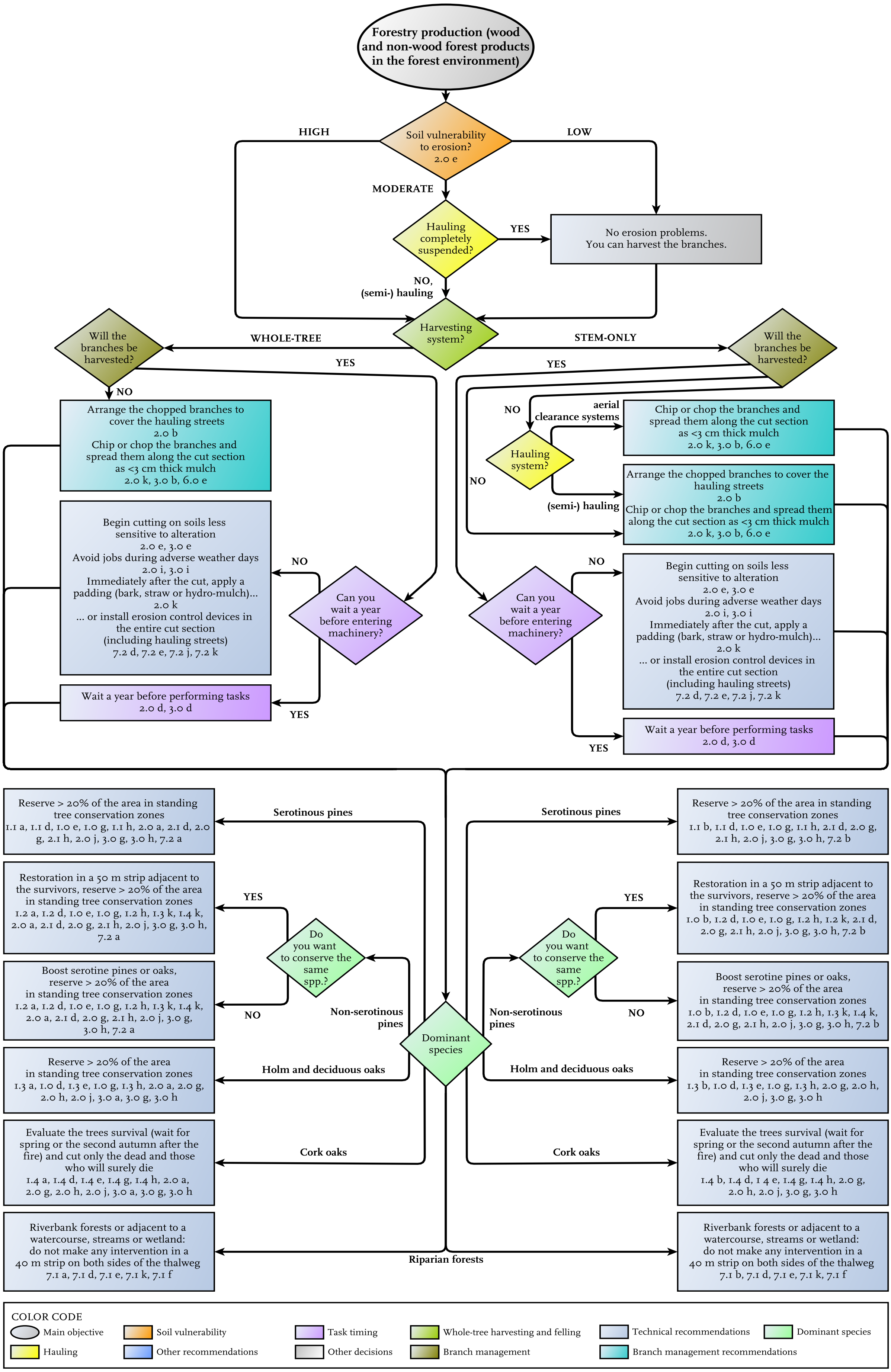
When the objective is the **creation of open habitats**, a key issue in the flow diagram is whether silvopastural use will be made of the burned area. This objective may also be motivated by maintaining open-habitat flora and fauna in regions where these are not very widespread. The fourth objective, subsequent fire risk reduction, directs the manager towards best practices for reducing the amount of available fuel for a possible future fire.

Immediately after fire, soil is the most vulnerable resource.[161] Accordingly, soil vulnerability to erosion is a key issue and one of the first to be addressed in the diagrams. The proposed method for soil evaluation is taken from *Guía técnica para la gestión de montes quemados. Protocolos de actuación para la restauración de zonas quemadas con riesgo de desertificación*[1], but *Acciones urgentes contra la erosión en áreas forestales quemadas - Guía para su planificación en Galicia*[161] can also be used. It is important that soil vulnerability to erosion is not conceived as a mean value for the entire burned area. On the contrary, the burned area must be mapped in zones with homogeneous vulnerability[1] and implement the specific recommendations for each zone.

Finally, the seasons of the year mentioned for task timing are based on the most common case – summer fires. For fires occurring in other seasons, wait at least 4 months before taking machinery into areas with low soil vulnerability, 8 months for areas with moderate soil vulnerability, and one year for areas where soil vulnerability is high.

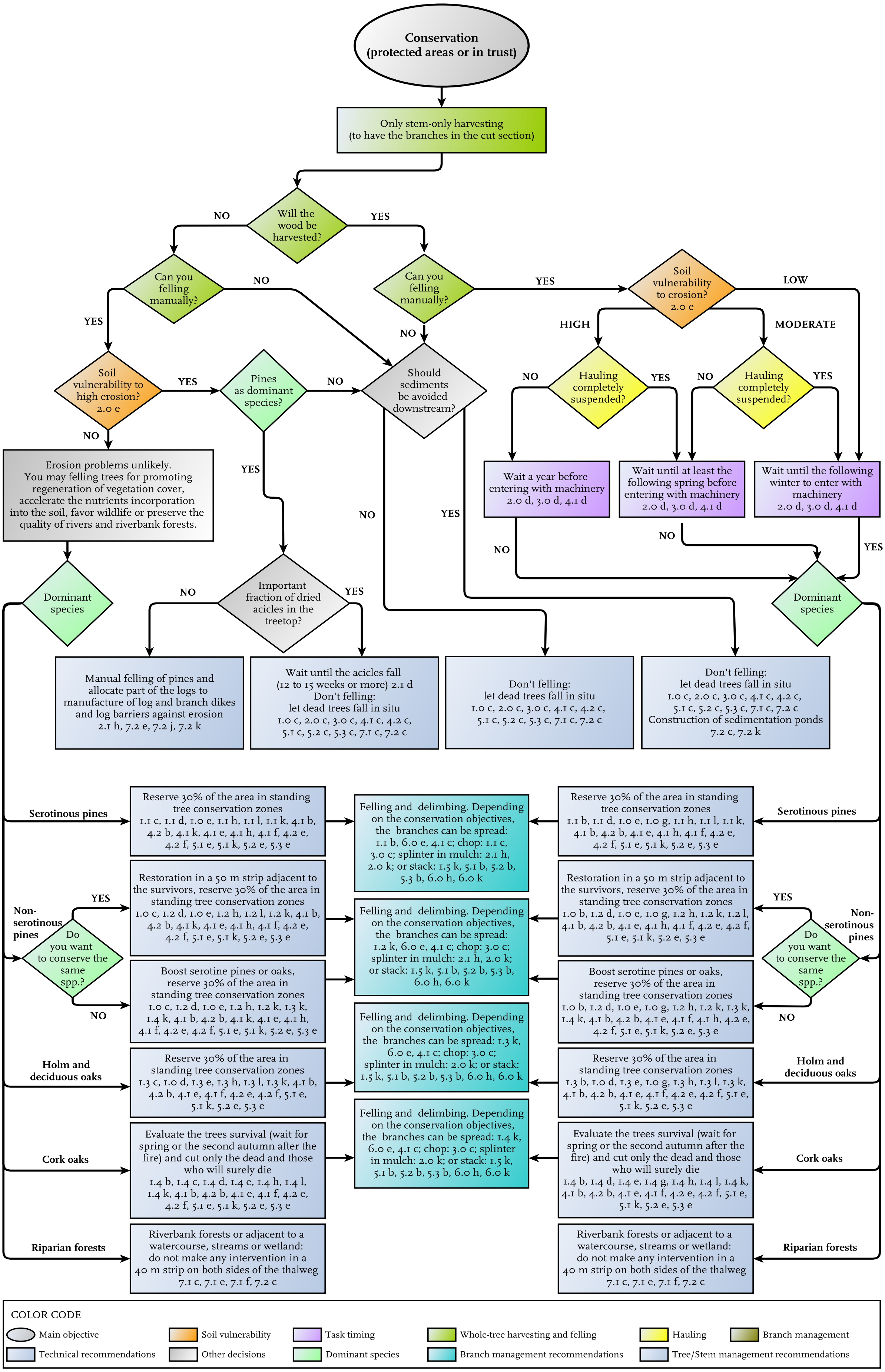
Below you will find the 4 flow diagrams, one for each objective, in a printable A4 format. A downloadable on-screen version is available on the *Anifog project website*, where each flowchart occupies one page (in PDF).

FLOWCHART 1. Forestry production (wood and non-wood forest products in the forest environment)



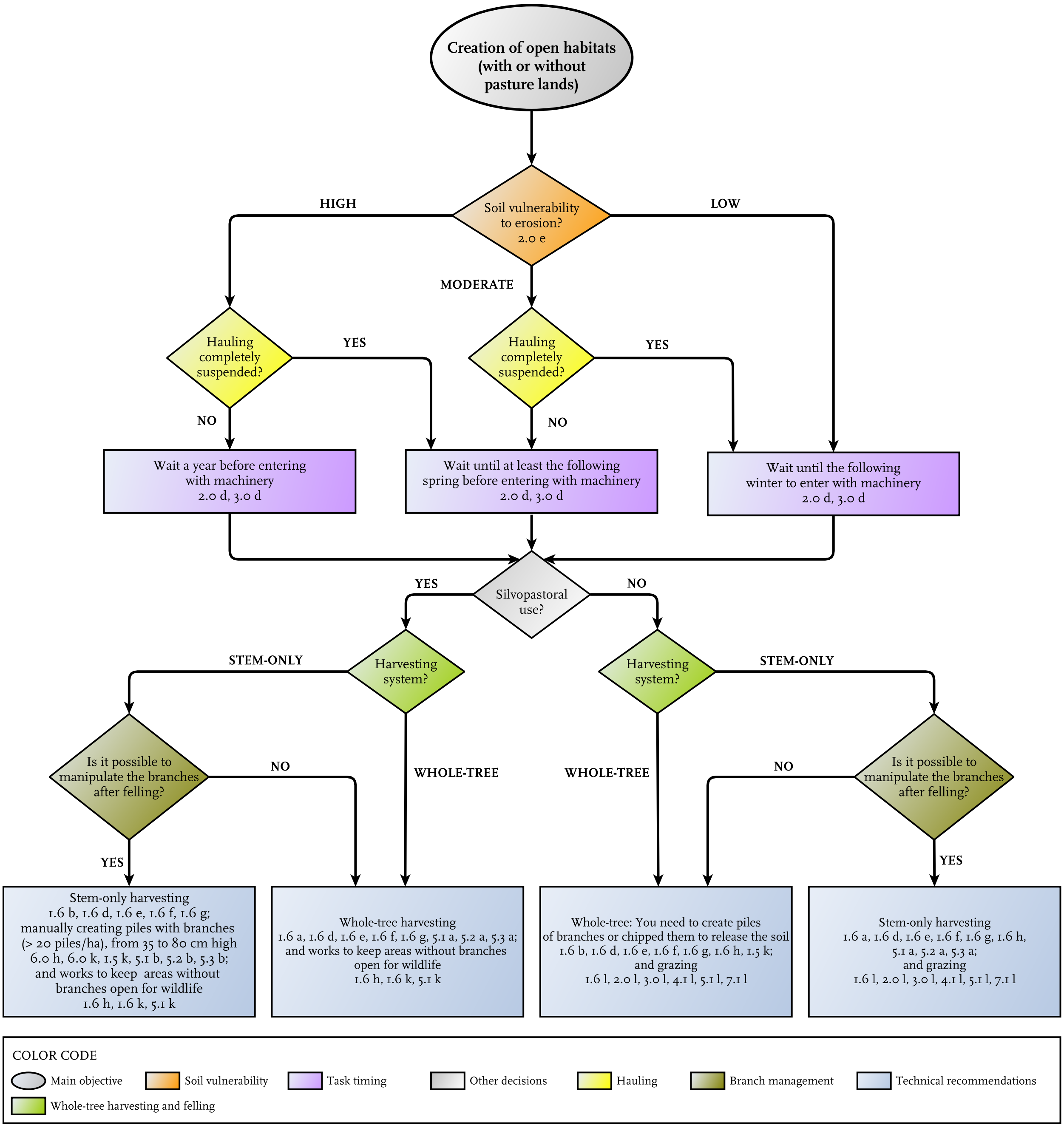
Codes in the tables (i.e. 1.4 b) correspond to the codes of good practice factsheets

FLOWCHART 2. Conservation (protected areas or in trust)



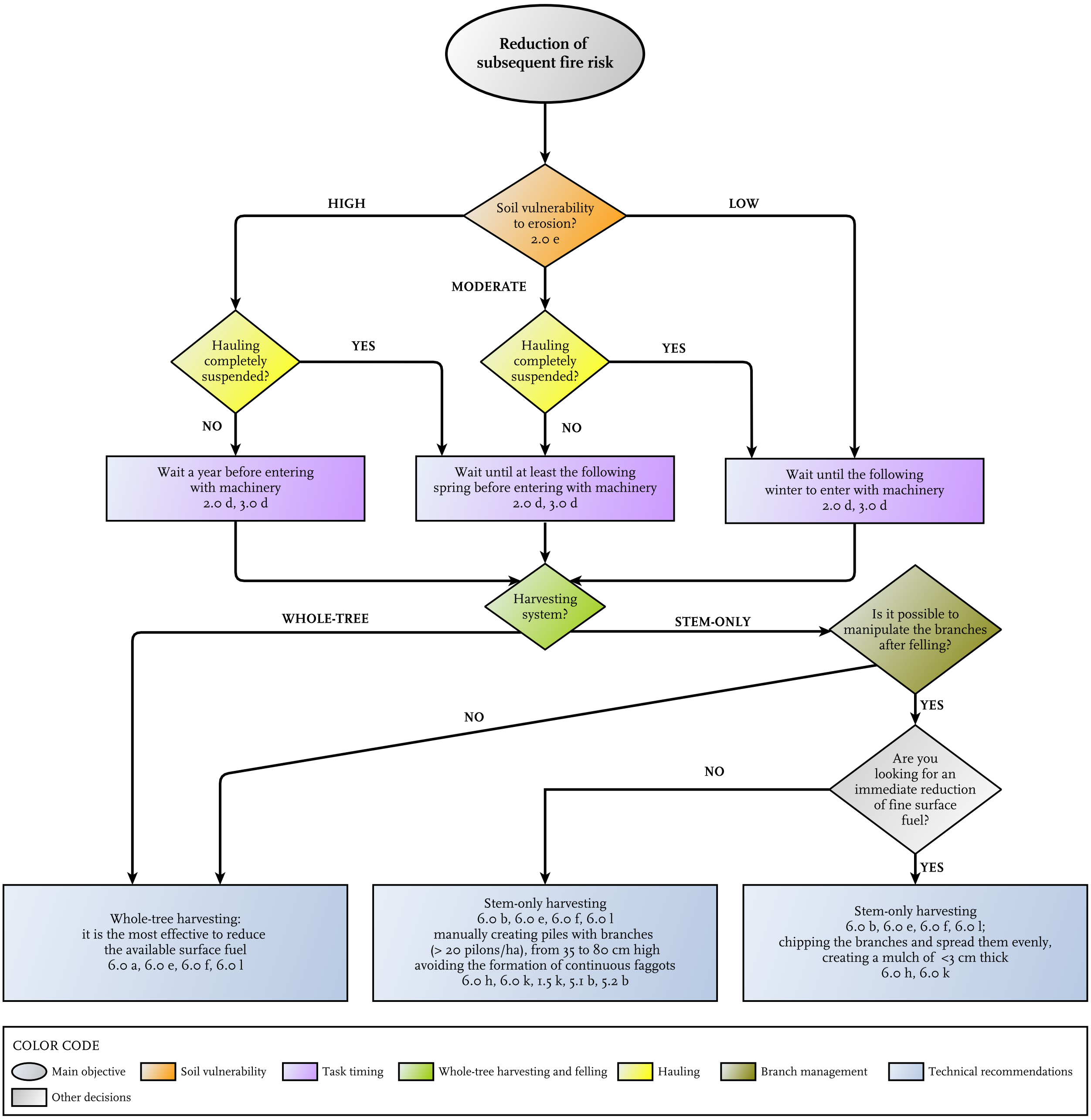
Codes in the tables (i.e. 1.4 b) correspond to the codes of good practice factsheets

FLOWCHART 3. Creation of open habitats (with or without pasture lands)



Codes in the tables (i.e. 1.4 b) correspond to the codes of good practice factsheets

FLOWCHART 4. Reduction of subsequent fire risk



Codes in the tables (i.e. 1.4 b) correspond to the codes of good practice factsheets

GOOD PRACTICE FILES FOR POST-WILDFIRE MANAGEMENT

In this section, we present the good practice files, which include recommendations for better post-wildfire management. To facilitate the link between the two parts of the files (the fundamentals and the good practice files), both come under the same title and are represented by the same colour:

The majority of the topics addressed in the good practice files are divided into more precise sections, identified by a second number (for example, according to dominant tree species; TABLE 1). When the section refers to the general conditions, the number is 0.

Each file has the same structure and consists of **12 groups of recommendations for forestry work** related to salvage logging. These are identified by a letter, from “a” to “l” (TABLE 1):

a. Whole-tree harvesting
b. Stem-only harvesting/ wood-chopping
c. No harvesting
d. Optimum time for logging
e. Location of logging sites
f. Logging intensity
g. Clearing
h. Site preparation
i. Climate conditions
j. Sloping land
k. Specific tasks
l. Silvopasteral benefits

Whenever possible, the different recommendation options have been listed in decreasing order of suitability for mitigating or avoiding the negative impacts of salvage logging: **BEST**, **MEDIUM**, **WORST** i **AVOID** (the latter indicating that actions should never be carried out).

Information has not always been found for all the recommendations. "**General**" indicates situations for which specific recommendations are not available, but recommendations in the "General conditions" section are applicable. "**No information**" indicates situations for which specific recommendations have not been found, but the "General conditions" recommendations are not applicable either.

Finally, possible contradictions between some recommendations must be highlighted. This is due to the fact that different environmental elements or varying objectives may require different management. It is up to managers to choose the most suitable recommendations for their objectives and for the means available to them to carry out the forestry work. You should be aware that adopting one recommendation to mitigate or avoid one impact may lead to the persistence of another.

1. PLANT COVER REGENERATION

1.0 General conditions

1.0 a Whole-tree harvesting

This is the least recommended harvesting system as it involves exporting more biomass.

FIGURE 4. Burned and felled Aleppo pines waiting for whole tree harvesting (a), next area after clearing (b). **Images:** P. Pons.

☞ **BEST.** Leave all the trees that show signs of life and those with dry leaves. The snags should be in clumps. Preserve all the burned scrub and avoid driving machinery over it.

☞ **MEDIUM.** Leave only the trees that show signs of life, harvesting those that have dry leaves. Some of the trees left standing can be in clumps, and others scattered. Machinery can be driven over the burned scrub, but do not chip them or chop them up.

☞ **WORST.** Cut and export all the biomass. Chip or chop the remaining biomass.

1.0 b Stem-only harvesting/ wood-chopping

☞ **BEST.** Leave the branches scattered around the logging strip. Leave the trees with signs of life standing. The snags left standing should be in clumps. Those with a charred canopy should be cut down, the branches cut off and everything left on the ground. Preserve all the burned scrub, and avoid driving machinery over it.

☞ **MEDIUM.** Leave the branches scattered around the logging strip. Leave the trees with signs of life standing. Some of the snags left standing can be in clumps, and other scattered. Those with a charred canopy should be cut down, the branches cut off and the stems cleared, but the branches should be left scattered uniformly over the site. Machinery can be driven over the burned scrub, but do not chip them nor chop them up.

☞ **WORST.** Cut and export all the biomass. Chip or chop the remaining biomass (scrub and small trees).

1.0 c No harvesting

☞ **BEST.** Leave around 10% of the snags standing, especially the most mature ones, and preferably in clumps. The rest should be cut and branches lopped off. Leave some of the branches scattered uniformly around the site being harvested,[78] and the rest should be manually placed in piles between 35 and 80 cm high distributed throughout the south-facing slopes of the logging strip.[132]

☞ **MEDIUM.** Leave around 10% of the snags standing, especially the most mature ones, some in clumps and others scattered. The rest should be felled and branches lopped off. Leave the branches scattered uniformly around the logging strip.[78]

☞ **WORST.** No intervention seems to be the least appropriate option when there is no post-fire harvesting.[78]

1.0 d Optimum time for logging

☞ **BEST.** Perform all the salvage logging operations before the saplings germinate or the stumps resprout so as not to damage plant regrowth. Stump resproutings are less sensitive to trampling.[78]

For serotinous pines this period can be very short because germination begins in the autumn and mortality caused by harvesting and clearing can affect more than 30% of plant regrowth.[45]

1.0 e Location of logging sites

☞ **BEST.** Machinery traffic should be restricted to the clearing roads to ensure that the least damage is done to plant regrowth (both trees and scrub). Apply good practices in any harvesting operation.

☞ **MEDIUM.** Apply good practices, especially in south-facing slopes where plant regrowth is slower and can be more adversely affected by salvage logging.

☞ **AVOID.** Restrict machinery traffic off the roads and no special attention is paid to south-facing slopes.

FIGURA 5. Effects of tree transport within the plot in the absence of roads. **Image:** P. Pons.

1.0 f Logging intensity

No information

1.0 g Clearing

☞ **BEST.** Clear the forest of the completely suspended wood using a self-loading trailer or an agricultural tractor, or packaged and suspended from a winch.[128] Machinery traffic should be restricted to the roads, which should be as spaced out as far apart as possible.

Clearing timber with channels is recommended if the wood is for use as firewood.[128]

FIGURA 6. Clearing on road by tractor and light self-loading trailer. **Image:** P. Pons.

☞ **MEDIUM.** Clear the area by semi-hauling with a skidder. The vehicle must get as close as possible to the felled trees so that they are completely dragged for the shortest possible distance. Do not drag the packs of chipped timber and excessively heavy loads.[128]

☞ **AVOID.** Avoid hauling the logs with an agricultural or forest tractor.[128] Compacted soil can make it more difficult for certain seeds to germinate, so avoid moving machinery on clayey soil when it is wet, as it is more easily compacted, and to a lesser extent, on dry and sandy or clayey soil.[128]

1.0 h Site preparation

The site does not need to be prepared unless there are stands of non-serotinous pines and the aim is to preserve the same species, or where the species are to be converted. To create a plantation and accelerate the regeneration of plant cover, it is best to plant the trees in holes rather than to plough the site, which disturbs the soil more.

1.0 i Climate conditions

No information

1.0 j Sloping land

No information

1.0 k Specific tasks

PLANTATIONS

☞ **BEST.** Tree planting should be carried out with as little ploughing as possible: ideally, small hollows should be made and the plant inserted into it. These hollows should be made manually on slopes of no more than 20% and in places with a high risk of soil erosion. The hollows can be made mechanically on slopes of less than 20%.[46]

MANAGING THE WOODY DEBRIS AND MULCH

Applying mulch, be it comprised of chipped debris (wood and/or branches and/or bark) or cereal straw, does not negatively affect the regeneration of the plant cover.[43,44]

☞ **AVOID.** With whole-tree harvesting or chopped-wood harvesting , do not burn the debris from the logging operation *in situ* as this slows down the regeneration of the vegetative cover and the richness of the plant cover.[9]

SAPLING THINNING AND LIVING-STUMP SELECTIONS

Sapling thinning and reshoot selections significantly reduce the fraction of canopy cover of the regenerating vegetation. However, these practices can improve the health of the stand and the ecosystem, increase resistance and resilience to fire, and create more heterogenous landscapes that facilitate preventative management.[35]

☞ **AVOID.** Avoid sapling thinning and reshoot selection before at least 60% of the soil is covered by leaf litter, grasses and/or scrub, and do not reduce the fraction of canopy cover below 60%.

1.0 l Silvopasteral benefits

Grazing in forests that are regenerating after burning can delay vegetation growth due to the consumption of apical meristems, especially by sheep and goats, as cows and horses prefer eating herbaceous plants. Saplings are more sensitive during the first five years of life. This damage is more frequent during dry years.[172] See the files on tree species for individual characteristics.

☞ **BEST.** Do not allow animals to graze in the regenerating forest areas while the apical meristems of the trees are within their reach. Forest management models (ORGEST) suggest fencing the pastures during the first five years after the fire.[11,12,118,119,162-164]

☞ **MEDIUM.** Prohibition measures can be lifted in years when there is more rain as there is more vegetation available for the animals.

☞ **AVOID.** Do not allow animals to graze. Even if the trees are protected with individual protectors, regeneration of the bush and grass cover can be delayed.

1. PLANT COVER REGENERATION

1.1 Serotinous pines

1.1 a Whole-tree harvesting

Regarding whole-tree harvesting, there are no studies that analyse the impact this has on plant cover regeneration. If salvage logging is carried out soon after fire, a lower sapling density is to be expected due to having exported branches with pine cones on them that did not open during the fire but would have opened later, freeing the pine nuts over the logged area. Moreover, the absence of logging debris creates an environment that is less conducive to the survival of regenerating vegetation, and these negative effects are even more marked if logging takes place after a second fire (15 years or less after the first fire, and where there were fertile pines).[151]

On the other hand, if the harvesting is done later, more damage can be caused to the already established saplings.

1.1 b Stem-only harvesting/ wood-chopping

Stem-only harvesting or chopped-wood harvesting does not endanger plant cover regeneration of Aleppo pine and **maritime pine** after fire, even if it is done after the seedlings have germinated (these pines mainly germinate during the first six months after fire which, if it was a summer fire, is in the autumn and winter).[158] If the salvage logging takes place after a second fire (15 years or less after the first fire, and where there are fertile pines), then the survival of the regenerating vegetation is negatively affected by the cumulative impacts of the three disturbances, despite the attenuation provided by the woody debris left in the logging strip.[151]

In an **Aleppo pine** harvesting operation carried out ten months after fire, where the trees were felled manually, hauling was effected with animal traction (mules) and the branches were also piled up manually, a density of 33,000 saplings/ha was achieved four years after the fire, despite a 62% mortality rate [94] (although without any intervention mortality rates are between 30 and 40% four to six years after the fire, with varying densities between 7,000 and 30,000 saplings/ha).[158] Similarly, in a **maritime pine** harvesting operation carried out 7 months after fire when the germination and initial growth of the seedlings was at its maximum, the mortality rate after 3 years was 61% and sapling density was 5.5 times higher in the harvested area than in the area where the trees had only been cut and the branches pruned.[20] This initial mortality could be beneficial by reducing sapling density, thus facilitating subsequent sapling thinning. In some cases, less upward growth is observed during the first years (compared with burned and uncut stands),[45] and in other cases upward growth is accelerated.[101]

With stem-only harvesting or chopped-wood harvesting, the main influence of the harvesting system employed is the amount of the branches left on the ground, which creates favourable microclimatic conditions for the resprouting of **Aleppo pine**[113] and **maritime pine.**[20] The branches have pine cones on them which would otherwise be exported, they do not provide root competition, and they reduce interspecies competition caused by resprouting scrub.[151] Generally, more branches should be left on south-facing slopes and in stands where the base area before the fire was smaller.

☞ **BEST.** Leave the branches scattered on the ground, covering between 50 and 75% of the soil. This way, densities of regenerating vegetation up to 100 times more abundant than when less than 1% of the soil is re-covered can be achieved.[113]

☞ **MEDIUM.** If some of the branches are to be exported for biomass, at least 25-30% of the soil must remain covered in branches in places where the pine regeneration may be scarcer: on south-facing slopes, in the stands with a small basal area before the fire and on unterraced slopes.[113]

☞ **WORST.** All the biomass can be exported, but leaving branches covering between 1% and 25% of the soil has significant positive effects on comparative regeneration after biomass removal.[113]

☞ **AVOID.** Do not pile up the branches using a forwarder if germination has already begun, as much of the regenerating vegetation can be destroyed.[45] This action is more damaging than chipping the woody debris in terms of regeneration mortality.[45,160]

1.1 c No harvesting

Greater densities and survival of saplings are obtained when there is no harvesting, but this is not always the case with the **maritime pine**,[19] which depends on how the biomass is processed.

☞ **BEST.** Cutting 90% of the trees and pruning the branches is recommended, leaving the timber on the ground covering approximately 45% of the surface area up to a height of between 0 and 10 cm, and 60% of the surface area up to a height of between 11 and 50 cm.[90] This reduces solar radiation and the temperature of the soil, while increasing its humidity ,[20] making saplings more vigorous, plentiful and sizeable, and increasing the number of pine trees.

☞ **MEDIUM.** A less costly practice is cutting the trees but not the branches. This option could reduce the degree of protection afforded to the saplings as it appears that the branches are more effective the nearer they are to the soil.

The timber does not need to be chopped up. In some cases this is beneficial to the nutrition of the saplings,[90] and in others it can be counterproductive.[20] Chopping the branches thus making the pine cones open up, however, can encourage a second cohort to appear if the first presents a high mortality rate.[45] Specific cases are the **maritime pine** with a low proportion of serotinous pines and stands where the canopies have largely remained uncharred, because chipping the branches can make the pine cones open up, freeing the pine seeds that otherwise would not germinate.[45,158]

☞ **WORST.** Not cutting any of the snags is the worst option as this leads to a lower sapling survival rate, possibly due to increased shade on the regenerating saplings of this species of pine, which does not tolerate shade well. This density, on the other hand, is enough to regenerate the stand.[20] In subsequent years, as the snags fall, up to 25% of the saplings can be damaged.[45]

1.1 d Optimum time for logging

☞ **BEST.** The best time for the salvage logging operation is before the pines germinate.[19] This time interval can be very short, because germination begins at the end of the autumn.[45] In the centre of the Iberian Peninsula, salvage logging during this window allows 45% of the maritime pine saplings to survive ten years after the fire.[19]

☞ **MEDIUM.** Pine survival in logging, clearing and woody debris management operations is directly related to their height and, most likely, to the development of the radicular system. It seems that delaying salvage logging for 12 months after the fire leads to a higher survival rate for the **maritime pine** [45] and probably for the Aleppo pine. On the other hand, carrying out salvage logging at the beginning or in the middle of the summer can pose a higher mortality risk due to hydric stress from increased exposure to solar radiation, especially if the summer is drier than usual.[158]

☞ **WORST.** Saplings are more sensitive in the first months after germination. It is not recommended to carry out forestry operations during these first months after germination (from November onwards) unless the sapling plantation is very dense and its partial destruction caused by machinery still leaves a density that ensures the regeneration de 2,000 trees/ha after ten years.[19] Only 20% of the **maritime pine** saplings germinated after fires survive when salvage logging takes place between November and January in the centre of the Iberian peninsula.

1.1 e Location of logging sites

General.

1.1 f Logging intensity

No information

1.1 g Clearing

General.

1.1 h Site preparation

This site does not require any intervention due to the abundant post-fire regeneration of this species.

1.1 i Climate conditions

No information

1.1 j Sloping land

No information

1.1 k Specific tasks

Sapling thinning accelerates the process to achieve a mass similar to prior to the fire, increasing the aerial seed bank and growth, [35] and promoting habitat diversity.[99]

1.1 l Silvopasteral benefits

Pine saplings are compatible with cow and horse grazing, but not sheep and goat grazing.

☞ **BEST.** Fence in grazing animals for five years after the fire.[11]

☞ **MEDIUM.** Fence in grazing animals for two or three years after the fire to control the development of the regenerating vegetation.[158]

1. PLANT COVER REGENERATION

1.2 Non-serotinous pines

1.2 a Whole-tree harvesting

As the establishment of saplings of this species after fire is scarce across a wide variety of conditions of plant competition,[123] and the aerial bank of pine nuts does not survive the fire, whole-tree harvesting has little impact on these species. See recommendation “1.2 d Optimal time for logging”, for when the most suitable moment to carry out salvage logging operations in stands of this species is.

☞ **BEST.** Preserve the live pines on the unburned patches of vegetation and on the unburned perimeter so that they can disperse their seeds over a short, adjacent strip of land.

1.2 b Stem-only harvesting/ wood-chopping

General.

1.2 c No harvesting

General.

1.2 d Optimum time for logging

☞ **BEST.** As the dispersal of **black pine** and **Scots pine (Scots pine)** pine nuts takes place in March and June, salvage logging on the adjacent strip less than 50 m from the unburned pines should be done before the spring of the year following the fire. This will avoid destroying the regenerating vegetation that has become established there, and it could also destroy the heliophile vegetation that has grown there that would shade the regrowing pine trees.

Because pine nut dispersal for the **stone pine** begins in the autumn, salvage logging in the adjacent strip less than 20 m from the unburned pines should be done as soon as possible to avoid destroying the regenerating vegetation that could germinate there that same autumn.

1.2 e Location of logging sites

General.

1.2 f Logging intensity

No information

1.2 g Clearing

General.

1.2 h Site preparation

To speed up the regeneration of the plant cover when creating a plantation to recover the composition of the mass to that prior to the fire or when converting the stand, it is recommended to plant the trees in holes and not to plough the land as this is more disturbing to the soil.

1.2 i Climate conditions

No information

1.2 j Sloping land

No information

1.2 k Specific tasks

☞ **BEST.** Preserve all the live pines and those whose canopy is partly uncharred. The **stone pine** is the species that best survives canopy fires and small clumps of live pines can often be found, which are vital for the regeneration of the burned areas.[123]

If the aim is to plant pines to regenerate plant cover, a profitability assessment must be made on the salvage logging operation when the value of timber is low. If there is no profit to be made from the timber, the least costly alternative may be to leave the snags standing, and go back and excavate hollows mechanically and plant conifers manually four years after the fire.[79]

One possibility for burned non-serotinous pine forests with weak regrowth and an absence of resprouting is to convert them into holm or deciduous oak forests by sowing acorns. The drawback with this method is seed predation mainly by rodents but also to some extent by wild boars (a ratio of 25 to 1).[77]

☞ **MEDIUM.** Rodents venture less into zones without plant cover, so as much of the biomass as possible should be removed from the areas where the acorns are to be planted. However, predation by wild boars will be greater, so this method can produce worse results in places with a high density of wild boars.

☞ **AVOID.** Avoid creating a complex habitat, leaving burned logs and branches on the ground of the logging strip. This creates obstacles for wild boars thus decreasing predation by this species, but it affords protection to rodents, thus increasing their activity. Using capsaicin as a mammal repellent does not provide any additional protection.

1.2 l Silvopasteral benefits

Pine saplings are compatible with grazing cows and horses, but not sheep and goats.

☞ **BEST.** For the five years immediately after the fire, fence in grazing animals on the strips adjacent to the patches of unburned vegetation and on the unburned perimeters.[12,118,119] Grazing on the rest of the area will depend on what vegetation is to be regenerated there.

☞ **MEDIUM.** For the two to three years immediately after the fire, fence in grazing animals on the strips adjacent to the patches of unburned vegetation and on the unburned perimeters to be able to monitor the development of the regenerating vegetation.[158] Grazing on the rest of the land area will depend on what vegetation is to be regenerated there.

1. PLANT COVER REGENERATION

1.3 Holm and deciduous oaks (except cork oaks)

1.3 a Whole-tree harvesting

To encourage resprouting, a smooth, clean cut without tears must be made close to the ground, so that rain water can run off easily.[163]

This is the least recommended harvesting system as it involves removing greater quantities of biomass.

1.3 b Stem-only harvesting/ wood-chopping

To encourage resprouting, a smooth, clean cut without tears must be made close to the ground, so that rain water can run off easily.[163]

1.3 c No harvesting

The snags can be left standing or cut. In this case, a smooth, clean cut without tears must be made close to the ground, so that rain water can run off easily.[163]

1.3 d Optimum time for logging

General.

1.3 e Location of logging sites

More abundant resprouting occurs where there is deeper soil and at the foot of valleys than in shallow soil, and also on north-facing as opposed to south-facing slopes. The total pluviometry does not appear to affect the number of resprouts, but the distribution of the rainy episodes does: if the rainy episodes are spread over time, there will be more resprouts.[39] Consequently, more intense stump selection is required where the soil is deeper and the slopes are north-facing.

1.3 f Logging intensity

No information

1.3 g Clearing

General.

1.3 h Site preparation

This site does not require any intervention due to the abundant post-fire repopulation of this species.

1.3 i Climate conditions

No information

1.3 j Sloping land

No information

1.3 k Specific tasks

To increase acorn production and in so doing **guide the transformation of the stand towards a seedling forest**, make a selection of the holm and deciduous oak stumps. Leave two or three sprouts per stump to decrease the vigour of the second sprouting.[41] While the stump selection increases their diametral and upward growth, biomass production and the basal area increase are greater in stands where no stump selection has been made. If the aim is to accumulate the greatest quantity of biomass in as short a time as possible, and to obtain a high fraction of canopy cover, do not do a second stump selection before at least 60% of the soil is covered in leaf litter, grasses and/or scrub.[35]

CONVERSION TO HOLM OR DECIDUOUS OAK FORESTS

If the **burned stands are comprised of non-serotinous pines**, they can be converted to a deciduous oak or holm oak forest at a low cost by means of acorn dispersion by jays, provided there are stands of deciduous or holm oaks nearby. The jay is one of the main agents of dispersal of acorns, spreading them up to hundreds of metres. The harvesting system will influence the dispersal of these seeds:

☞ **BEST.** Non-intervention in the burned pine forest is the best way of achieving the greatest density of deciduous and holm oak saplings. Pine snags provide a reasonable habitat for jays.[22]

☞ **MEDIUM.** Leave all the live trees and more than 10% of the snags standing (more than 150 trees/ha), leaving (all) the branches from the cut trees on the ground to attract a sufficient number of jays. Nonetheless, the density of saplings obtained will not be as great as when there is no intervention.[22] Unwanted burned and cut logs should be piled up in the burned area.

☞ **AVOID.** The salvage logging should not leave less than 10% of the snags standing, and branches must not be removed or chopped *in situ*.[22]

1.3 | Silvopasteral benefits

Where holm or deciduous oaks are cut to encourage resprouting, grazing must be excluded from the logging strip until the apical meristems are out of the animals' reach,[23] so fence the area off from herds for at least the first five years.[163]

In the case of shoot selections and thinning in standard models, it may be beneficial to pasture animals on the processed site in the first and second years after carrying out these actions to monitor the living stump.[163]

1. PLANT COVER REGENERATION

1.4 Cork oaks forests

1.4 a Whole-tree harvesting

Given their remarkable capacity for regeneration, the future viability of a tree must be ensured before it is cut. In general, it is best to wait until the spring or even the second autumn after the fire to evaluate the state of health of the tree population and then take a decision. If the bark has been almost entirely consumed by the fire, open it up and if it comes away from the trunk then the cambium is dead. If the surface area of the dead mother layer is larger than 40% of the circumference, the trees are no longer viable and they have lost their economic value. The decision to cut the tree and regrow it from sprouts must then be considered. In many cases, the stumps sprout almost immediately and quite energetically.[162]

To encourage resprouting, the trees must be cut close to the ground with a smooth, clean cuts without tears, so that rain water can run off easily.[163]

1.4 b Stem-only harvesting/ wood-chopping

Given their remarkable capacity for regeneration, the future viability of a tree must be ensured before it is cut. In general, it is best to wait until the spring or even the second autumn after the fire to evaluate the state of health of the tree population and then take a decision. If the bark has been almost entirely consumed by the fire, open it up and if it comes away from the trunk then the cambium is dead. If the surface area of the dead mother layer is larger than 40% of the circumference, the trees are no longer viable and they have lost their economic value. The decision to cut the tree and regrow it from sprouts must then be considered. In many cases, the stumps sprout almost immediately and quite energetically.[162]

To encourage resprouting, the trees must be cut close to the ground with a smooth, clean cuts without tears, so that rain water can run off easily.[163]

1.4 c No harvesting

Given their remarkable capacity for regeneration, the future viability of a tree must be ensured before it is cut. In general, it is best to wait until the spring or even the second autumn after the fire to evaluate the state of health of the tree population and then take a decision. If the bark has been almost entirely consumed by the fire, open it up and if it comes away from the trunk then the cambium is dead. If the surface area of the dead mother layer is larger than 40% of the circumference, the trees are no longer viable and they have lost their economic value. The decision to cut the tree and regrow it from sprouts must then be considered. In many cases, the stumps sprout almost immediately and quite energetically.[162]

To encourage resprouting, the trees must be cut close to the ground with a smooth, clean cuts without tears, so that rain water can run off easily.[163]

1.4 d Optimum time for logging

Cork oaks are more sensitive to fire during the period when they are most active biologically, which is from March to June.[23] If the fire happens in spring, it may be more difficult for the plant cover to regenerate because the apical meristems located in the branches and the stem will die and resprouting will occur from the ones located on the stump or on the neck of the roots that have best survived the fire.

1.4 e Location of logging sites

South-facing cork oaks are more vulnerable to fires than north-facing cork oaks.

1.4 f Logging intensity

No information

1.4 g Clearing

By the time forest clearing takes place (a year or more after the fire), the surviving cork oaks will already have resprouted, so care must be taken not to damage them. Machinery movement must be restricted to the hauling roads to cause minimum harm to possible resprouts of both trees and scrub.

1.4 h Site preparation

This site does not require any intervention due to the abundant post-fire repopulation of this species.

1.4 i Climate conditions

No information

1.4 j Sloping land

No information

1.4 k Specific tasks

When cutting cork oak trees so that they can resprout from the stump, make a stump selection to improve both cork and acorn production, and to direct the stand towards a seedling forest. Leave two or three sprouts per stump to decrease the vigour of the second resprouting.[41] Select the straight resprouts growing on the stump, spaced at least 50 cm apart.[162] While the stump selection increases their diametral and upward growth, biomass production of biomass and the basal area increase are greater in stands where no stump selection has been made. If the aim is to accumulate the greatest quantity of biomass in as short a time as possible, and to obtain a high fraction of canopy cover, do not do a second stump selection before at least 60% of the soil is covered in leaf litter, grasses and/or scrub.[35]

CONVERSION TO CORK OAK FORESTS

If the **burned stands are comprised of non-serotinous pines**, they can be converted to a cork oak forest at a low cost by means of acorn dispersion by jays, provided there are stands of deciduous or holm oaks nearby. The jay is one of the main agents of dispersal of acorns, spreading them up to hundreds of meters. The harvesting system will influence the dispersal of these seeds:

☞ **BEST.** Non-intervention in the burned pine forest is the best way of achieving the greatest density of deciduous and holm oak saplings. Pine snags provide a reasonable habitat for jays.[22]

☞ **MEDIUM.** Leave all the live trees and more than 10% of the snags standing (more than 150 trees/ha), leaving (all) the branches from the cut trees on the ground to attract a sufficient number of jays. Nonetheless, the density of saplings obtained will not be as great as when there is no intervention.[22] Unwanted burned and cut logs should be piled up in the burned area.

☞ **AVOID.** The salvage logging should not leave less than 10% of the snags standing, and branches must not be removed or chopped *in situ*.[22]

1.4 l Silvopasteral benefits

Where cork oaks are cut to encourage resprouting, grazing must be excluded from the logging strip until the apical meristems are out of the animals' reach,[23] so fence the area off from herds for at least the first five years.[163]

In the case of stump selections and thinning in standard models, it may be beneficial to pasture animals on the processed area in the first and second years after carrying out these actions to monitor the living stump.[163]

1. PLANT COVER REGENERATION

1.5 Understory vegetation

1.5 a Whole-tree harvesting

General.

1.5 b Stem-only harvesting/ wood-chopping

General.

1.5 c No harvesting

General.

1.5 d Optimum time for logging

General.

1.5 e Location of logging sites

General.

1.5 f Logging intensity

No information.

1.5 g Clearing

General.

1.5 h Site preparation

General.

1.5 i Climate conditions

No information

1.5 j Sloping land

No information

1.5 k Specific tasks

The branches of the cut trees can be used to make piles or faggots. These piles of branches between 35 and 80 cm high do little to control erosion (see file "7.2 Erosion control procedures"), but they do attract frugivorous birds who disperse the seeds of fleshy-fruit plants (possibly due to their similarity to scrub). Therefore, seed density under the piles is similar to that in the soil of the adjacent unburned forests. Seed density under the scattered snags in the burned area is lower, and intermediate seed density has been recorded in clumps of snags and in open areas (between piles). It would therefore appear that scattered snags are not used by frugivorous birds as a perch,[136] but they are used by other species with different eating habits to find food, perch, roost, nest and survey the area.[84]

The effects of the piles of branches are significant on south-facing slopes, where almost as dense a covering of fleshy-fruit plants outside the piles is achieved as on north-facing slopes. The highest piles are better to recruit fleshy-fruit plants. The effect of these piles (which in the study covered between 5 and 10% of the burned surface area) is not dependent on the distance from the unburned forest. They can therefore serve to encourage fleshy-fruit plants to recolonise the most interior parts of the burned areas, not only in the piles themselves but also between them.[132,136]

FIGURE 7. Piles made in April 2017 with burnt branches (a) and only one year later (b), in a stone pine forest with burnt cork oaks in July 2016. **Images:** P. Pons.

For forests of strawberry tree resprouts, a stump selection can be made to accelerate growth. However, bear in mind that a selection of stools must be carried out the following year and the more intense the first selection was, the more stools there will be. Understory clearing has no impact.[121]

1.5 | Silvopasteral benefits

General.

1. PLANT COVER REGENERATION

1.6 Conversion of tree-covered areas towards open habitats

1.6 a Whole-tree harvesting

Whole-tree harvesting encourages the conversion of burned stands, especially those made up non-serotinous pines, into open habitats, in particular after severe fires. Eliminating branches facilitates subsequent silvopastoral use.

Where the fire was less severe and some of the mature trees have survived, some of them can be cut to ensure conversion into a sparsely wooded pasture, scrub or grassland.

For conversion into a sparsely wooded pasture, the recommended densities of live, mature trees (or stumps in the case of holm and deciduous oaks) to retain during the salvage logging are [6,40,57]:

Holm and **deciduous oaks**: between 400 and 1,000 stumps/ha selected, or no more than 60% of the canopy cover.

Black pine and **scots pine**: between 350 and 650 trees/ha.

Stone pine: between 100 and 300 trees/ha.

1.6 b Stem-only harvesting/ wood-chopping

Whole-tree harvesting encourages the conversion of burned stands, especially those made up non-serotinous pines, into open habitats, in particular after severe fires. Eliminating branches facilitates subsequent silvopastoral use.

Where the fire was less severe and some of the mature trees have survived, some of them can be cut to ensure conversion into a sparsely wooded pasture, scrub or grassland.

For conversion into a sparsely wooded pasture, the recommended densities of live, mature trees (or stumps in the case of holm and deciduous oaks) to retain during the salvage logging are [6,40,57]:

Holm and **deciduous oaks**: between 400 and 1,000 stumps/ha selected, or no more than 60% of the canopy cover.

Black pine and **scots pine**: between 350 and 650 trees/ha.

Stone pine: between 100 and 300 trees/ha.

1.6 c No harvesting

SEROTINOUS PINES

Unharvested stands of serotinous pines can be converted to open habitats through the prescribed burning of sapling regrowth, the thicket stage or the pole stage before the pine cones are produced, and this is more easily achieved in stands of maritime pines with a small proportion of serotinous pines.[4,158]

NON-SEROTINOUS PINES

The conversion of stands of unharvested non-serotinous pines to open habitats after fire will depend on the severity of the fire and the presence of resprouting. In less severe cases (especially where there are mature pines) and/or where holm or deciduous oaks are the accompanying species, these pine forests will only remain open temporarily.[5,6,57]

If no harvesting is carried out, the snags will progressively fall down and this process will accelerate from the third year after the fire onwards. This tree debris can hamper later actions to maintain an open habitat. These actions include grazing (impeding the animals' movement), and controlled burns to eliminate tree regeneration (due to the large fuel load in the area, which can either hamper or assist the burn, depending on each case).

HOLM AND DECIDUOUS OAKS

The likelihood of unharvested holm and deciduous oak forests evolving into scrub or grassland after fire is low. Resprouts quickly occupy the space after the fire, creating a transitory holm and/or deciduous oak sprout thicket that will create a small, closed wood.[40]

1.6 d Optimum time for logging

If the aim is to reduce the tree cover in the future stand, the most suitable moment for logging seems to be a year after the fire, by which time the regenerated vegetation is established and can be partially damaged or destroyed by logging and clearing activity.

1.6 e Location of logging sites

On south-facing slopes and less developed soil, the regeneration (by both seeds and resprouting) is less vigorous, so here it will be easier to steer the transition from a tree environment habitat to an open one.

AREAS FOR PROMOTING FOREST MANAGEMENT

The Areas for Promoting Forest Management (APFM) are ideal locations for converting tree habitats to open habitats if post-fire conditions permit.

The APFMs are areas where strategic actions are implemented to intervene in a fire's maximum capacity to propagate, thus indirectly generating a larger window of opportunity for control. To reduce the risk of a second fire, it is recommended that the post-fire action should be whole-tree harvesting or, where stem-only harvesting is carried out, the woody debris is eliminated by chipping/chopping *in situ* or on the trail. Leaving the woody debris spread on the ground in sections is not recommended.[11] For the different types of fires that occur in Catalonia, the APFMs are:

Bottom of ravines and the intersection of ravines, in areas affected by topographic fires.

High parts of south-, south-west and west-facing crests, in areas affected by convective fires with or without wind.

Recessed and wind protected areas, in areas affected by wind-driven fires.

Intersections of crests, in areas affected by wind-driven fires.

Mountain pass, in areas affected by wind-driven fires.

The size of the area to be considered varies depending on specific characteristics, but a minimum width of 60 m can be set as a guideline (for example, at the intersection of a ravine, 30 m from one side of the thalweg line to the other).[11]

AERIAL PHOTOGRAPHS

Old aerial photographs are a useful guide when recovering open habitats in tree-covered areas as they can locate old crops and forested pastures. These previously cultivated areas are flatter (so there is less risk of erosion) and more fertile (so the plant cover regenerates faster).

1.6 f Logging intensity

CONVERSION TO A SPARSELY WOODED PASTURE

For conversion into a sparsely wooded pasture, the recommended densities of live, mature trees (or stumps in the case of holm and deciduous oaks) to retain during the salvage logging are [6,40,57]:

Holm and **deciduous oaks**: between 400 and 1,000 stumps/ha selected, or no more than 60% of the canopy cover.

Black pine and **Scots pine**: between 350 and 650 trees/ha.

Stone pine: between 100 and 300 trees/ha.

CONVERSION TO GRASSLAND OR SCRUB

For conversion into grassland or scrub with no tree cover, the timber must be harvested more intensely, in line with the recommendations set out in File "0 Post-fire Management and Planning at Landscape Level".

1.6 g Clearing

If the aim is to reduce the amount of tree cover in the future stand, roads are not required for clearing and the machinery can move freely, damaging or destroying part of the regenerating vegetation. This can harm grass regeneration. However, the soil must still be protected from erosion, and soil fertility, fauna and riverine and riparian habitats must also be conserved. The vulnerability of these elements must therefore be evaluated before allowing machinery to move extensively around the burned area.

1.6 h Site preparation

Ploughing is unnecessary because the aim is to create an agricultural habitat, not a forest one, so conserving the biodiversity of open habitats is not as much a priority. In some cases, meadow plants could be sowed, which would require working the land.

1.6 i Meteorologia

No information

1.6 j Sloping land

No information

1.6 k Specific tasks

STANDS OF SEROTINOUS PINES

If serotinous pine regeneration is abundant and the aim is to convert the area into an open habitat, the sapling regrowth, the thicket-stage and the pole stage can be eliminated by intense controlled burns or by mechanical means before the pines produce cones (around 15 years for Aleppo pine and 10 years for maritime pine).

1.6 l Silvopasteral benefits

Silvopastoral harvesting is the best way to maintain open habitats.

CONVERSION TO SPARSELY WOODED HOLM AND DECIDUOUS OAK PASTURES

A living-stump selection must be made after the fire, preserving between 400 and 1,000 stumps/ha.[40] Grazing on the logging strip must be excluded immediately afterwards and until the apical meristems are out of the animals' reach,[23] so fences must be erected to keep all herds out of the area for the first five years,[163] because cows, sheep and goats all eat the tender shoots of holm oaks, in addition to the leaves in the case of cows and goats. Fenced deciduous oak stands can be opened up for grazing by cows in the winter when they cannot graze on the leaves (eaten in abundance in May and June). This does not apply to the holm oak, the leaves of which are consumed all year round.[153]

After this period without any access for animals, the living stump of new sprouts can be controlled by grazing in the processed area,[163] as the new resprouts will still be accessible to the animals and the dominant resprouts to cows.[41] Nonetheless, a clearing operation will probably be required to reduce bush cover, increase the availability of grass and stimulate the production of tender shoots, depending on the species grazing there.[40]

CONVERSION TO SPARSELY WOODED NON-SEROTINOUS PINE PASTURES

Post-fire, stands can be converted to sparsely wooded pastures if between 350 and 650 live stumps/ha remain in the case of Scots pine and black pine,[6] and between 100 and 300 live stumps/ha remain in the case of stone pine.[118] The animals themselves will stop tree cover impeding pine regeneration. Goats consume large amounts of aciculas, whereas for sheep this is an occasional source of food, preferring Scots pine and black pine. Cows do not consume regenerating pine trees, but they do lower the survival rate due to trampling.[6]

CONVERSION TO SCRUB OR GRASSLAND

Maintaining these communities depends largely on the type of animals grazing there. **Cows** consume large amounts of false brome grass (*Brachypodium retusum*), purple false brome (*Brachypodium phoenicoides*), blue aphyllanthes (*Aphyllantes monspeliensis*) and orchard grass (*Dactylis glomerata*), whereas of the woody species they only consume holm oak leaves (mainly in winter) and deciduous oak leaves (mainly in spring). **Sheep** consume blue aphyllanthe, orchard grass and albaida broom (*Anthyllus cytisoides*), but not spiky fescue (*Festuca gautieri*), false brome grass and purple false brome; of the woody species, they only eat the flowers and leaves of rosemary (*Rosmarinus officinalis*), tender holm oak shoots and occasionally pine aciculas. **Goats** consume little grass, but a lot of woody plants such as pine aciculas, the tender shoots and leaves of the holm oak, snowy mespilus (*Amelanchier ovalis*), kermes oak (*Quercus coccifera*), Mediterranean buckthorn (*Rhamnus alaternus*), blackthorn (*Prunus spinosa*), Mediterranean heather (*Erica multiflora*) and rosemary, in addition to gorse fruit (*Ulex parviflorus*). They do not eat thyme or rock rose (*Cistus* spp.).[6,40]

2. REDUCTION OF SOIL EROSION

2.0 General conditions

2.0 a Whole-tree harvesting

☞ **BEST.** Preserve as much of the ash, burned debris and leaf litter as possible, as these help retain rainwater.[144,159] Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space the roads out as far apart as possible.[128] Leave clumps of snags in the areas most susceptible to erosion.

☞ **AVOID.** Avoid whole-tree harvesting across the entire burned area. Do not allow vehicles with chains to circulate.[161]

2.0 b Stem-only harvesting/ wood-chopping

☞ **BEST.** Prioritise whole-tree harvesting or chopped-wood harvesting: fell the trees closest to the roads first, ensuring that they fall crossways to the trail and that the debris from the debranching and chopping stays where it is to lessen the negative effect of circulating agricultural tractors and skidders on the soil.[128] Leave tress in clumps in the areas most susceptible to erosion.

Preserve as much of the ash, burned debris and leaf litter as possible, as these help retain rainwater.[144,159] Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space the roads out as far apart as possible.[128]

☞ **AVOID.** Avoid whole-tree harvesting across the entire buned area. Do not allow vehicles with chains to circulate.[161]

2.0 c No harvesting

☞ **BEST.** This management practice should always be considered.[50] Cutting the trees manually with a chainsaw is recommended rather than mechanical operations when the trees are felled and the branches cut for other uses.

2.0 d Optimum time for logging

☞ **BEST.** Wait at least one year before taking machinery into the forest.[137] For summer fires, wait until at least the following spring before intervening to avoid disturbing the soil before the autumn storms.[144] This delay allows the leaves and aciculas of the charred trees to fall, providing the soil with a protective layer.[159]

Begin harvesting on the north-facing slopes. The soil on the south-facing slopes is more fragile and superficial, and the vegetation takes longer to regenerate there after fire.[2] On the north-facing slopes the vegetation not only regenerates sooner, but it also burns less intensely and produces more ash and debris that protects the deeper soil there.[91] More care must be taken with the soil on the south-facing slopes. Less stony soil is also more sensitive.[144] Begin harvesting on the stonier soil.

Programme forestry work for when the soil is humid (autumn, winter and spring) to avoid machinery traffic when the soil is more hydrophobic (in summer), which increases the risk of erosion.[137]

☞ **MEDIUM.** Wait at least one year before taking machinery into the forest.[137] For summer fires, wait until at least the following spring before intervening to avoid disturbing the soil before the autumn storms.[144]

☞ **WORST.** Wait at least four months before taking machinery into the forest.[2]

2.0 e Location of logging sites

How vulnerable the soil is to erosion is related to its lithology (mother rock), the slope, the proportion of surface area of naked soil, the thickness of the layer of leaf litter,[1] and the type of fire. Avoid salvage logging the trees, creating new roads and roads, circulating machinery off the roads and hauling the stems where the soil is at maximum risk of erosion.[158]

Low vulnerability: Soil formed from limestone, dolomite, limestone with dolomite or calcarenite, or limestone and sandstone, with a slope of $< 15\%$, a surface area of naked soil of $< 30\%$, and where the thickness of leaf litter is > 3 cm.

Moderate vulnerability: Soil comprised of marlstone, calcarenite, soft limestone, conglomerate, conglomerate and clay, limestone and marl, flysch, calcarenite and marl, dolomite and marl, sandstone, slate, or schist and quartzite, with a slope of between 15 and 30%, a surface area of naked soil of between 30 and 60%, and where the thickness of leaf litter is between 1 and 3 cm.

High vulnerability: Soil comprised of granite, conglomerate with clay, sand, clay, clay with sand, chalk, marl, or clay with marl or with silt, with a slope of > 30%, a surface area of naked soil of > 60%, and where the thickness of leaf litter is < 1 cm.

2.0 f Logging intensity

Lower intensity logging operations require less erosion control measures.

2.0 g Clearing

☞ **BEST.** Reduce the distance the timber is dragged or semi-dragged to the minimum. Clear the forest of the completely suspended wood using a self-loading trailer or an agricultural tractor, or packaged and suspended from a winch (for the chipped wood).[86,128,168] Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space them out as far apart as possible.[128] If the density of marked roads is low and there is excessive circulation of vehicles along them, this could damage the soil.[128,168]

Do a preliminary survey and, where necessary, mark the clearing roads and accurately locate the points where the timber will be accumulated to minimise the dragging distances inside the stand being harvested.[119]

Clearing timber with channels is recommended if the wood is to be used as firewood.[128]

For whole-tree harvesting or chopped-wood harvesting, the harvesting debris (mainly the branches) can have uses other than preventing erosion (see files “1. Plant cover regeneration” and “5. Conservation of vertebrate fauna”), as leaving the logging debris unprocessed in not very efficient.[168] Where the whole-tree harvesting is done manually, cut some of the branches before clearing to leave them *in situ* for the same purposes.

☞ **MEDIUM.** When clearing the area by semi-hauling with a skidder, the vehicle must get as close as possible to the felled trees so that they are completely dragged for the shortest possible distance. Do not drag the packs of chopped timber and excessively heavy loads.[128]

☞ **AVOID.** Avoid hauling the logs with an agricultural tractor or a skidder.[128] Compacted soil can impede seed germination, so avoid circulating with machinery on clayey soil when it is wet, as it is more easily compacted, and to a lesser extent, on dry and sandy or clayey soil.[128] Do not allow the vehicles with chains to circulate.[161]

2.0 h Site preparation

☞ **BEST.** Tree planting should be carried out with as little ploughing as possible: ideally, small hollows should be made and the plant inserted into it. These hollows should be made manually on slopes of no more than 20% and in places with a high risk of soil erosion. The hollows can be made mechanically on slopes of less than 20%.[46]

☞ **AVOID.** Avoid deeply ploughing the land as this action increases erosion immediately after the fire beyond the natural levels of the soil.[144]

2.0 i Climate conditions

☞ **BEST.** Avoid carrying out mechanised tasks on very rainy days when the runoff on the soil where the machinery is circulating can be high,[128] and on windy days when the wind can blow away the ash disturbed by the machinery.

☞ **AVOID.** During the first year after a moderate or severe fire, do not circulate with machinery in the forest when the soil is excessively humid, frozen or snow-covered, because this causes deterioration in its structure.[144]

2.0 j Sloping land

For clearing using machinery, follow these recommendations depending on the slope [128]:

Slope < 25%: preferably use a self-loader rather than an agricultural tractor.

Slope 25% – 35%: the skidder is more efficient, but limited when using the self-loader.

Slope 35% – 60%: preferably use a skidder, or clear the forest using an aerial cable on slopes of more than 50%.

Slope > 60%: clearing with an aerial cable is preferable, rather than hauling with cables from the trail.

Post-fire risk of erosion is generally low if the slope is less than 20%. On more sloping land, the risk is higher only when the fraction of the burned surface area covered in leaf litter that has fallen from the charred canopy is below 66% .[159]

2.0 k Specific tasks

These tasks (mainly mulch and sewing grasses) are not specifically required provided that good practices are applied during the salvage logging operation and the site is not especially sensitive to erosion and runoff (steep slope and slow regeneration of the vegetation cover).[158] Nonetheless, the burned area must always be evaluated to detect the spots most susceptible to soil degradation in order to apply appropriate measures.[50] Generally, Mediterranean soils conserve a similar infiltration capacity after fire, although there are occasional cases of hydrophobia induced by the fire. Despite a considerable increase in surface runoff during the first year after fire, there is no significant increase in erosion.[146] Provided the vegetation and the leaf litter have not been destroyed during harvesting, the runoff and the erosion in Quercus species and pine stands return to their pre-fire levels after one to three years.[146] The colour of the ash can be an indicator of the severity of the fire. If the ash deposited on the soil is reddish, black or dark grey in colour, then the fire was not very severe, and the particles of ash will be big enough so as not to obstruct the pores of the soil and the forest will probably require no intervention to regenerate.[13]

Erosion prevention measures must be applied in key locations due to the impossibility of applying them across the entire burned surface area.[46] These measures must be applied in severely burned basins, steeply-sloping areas and zones with superficial or bare soil, or soil that repels water (hydrophobia induced by the fire), where the vegetation could naturally take more than four years to recover.[146]

☞ **BEST.** Applying mulch is the most efficient treatment. Covering at least 70% of the soils with mulch made from the woody debris of the salvage logging that has been chipped and chopped to increase its contact with the soil, can reduce erosion by up to 90% compared with an untreated burned area.[46] If there is no woody debris because there was no salvage logging, mulch made from straw and chipped bark produces the best results.[43,44]

To improve its effectiveness, the seeds of native grass species can be mixed with the mulch.[55] This technique should be prioritised on steep slopes with little vegetation cover and a high risk of erosion, and it should be applied soon after the fire and before the autumn rains.[158] In low to moderate severity fires, the mulch made from woody debris can be obtained naturally, leaving enough time for the leaves and the aciculas from the charred canopies to fall to the ground.

The microtopography also influences erosion. Abandoned, forested agricultural terraces also afford the soil protection against erosion after fire. Preserve these terraces during harvesting operations.[107]

☞ **MEDIUM.** The effectiveness of growing grasses largely depends on the pluviometry and the temperature. Apply the seeds in combination with another measure that takes effect before germination and protects the seeds and the seedings, such as mulch or hydro-mulch application, if not the seeds can be borne away by the runoff before they germinate.[46]

☞ **AVOID.** Avoid sewing foreign grasses which displace native vegetation.[46]

Not processing the logging debris [168] or using it to construct obstacles parallel to the contour lines (with stems and branches, or bales of hay/straw) are not very effective ways to control erosion, especially when there are torrential rains, which are frequent during the autumn.

Avoid scarifying or ploughing the soil to facilitate the infiltration of rain water, especially on hydrophobic soil, as this only encourages erosion.

2.0 l Silvopasteral benefits

☞ **AVOID.** Avoid allowing animals to graze on the site in the months following the fire, as this can considerably reduce the abundance of grass and scrub species, which are highly digestible and attractive to herbivores, but whose roots retain rainwater and stabilise and structure the soil and, in the case of leguminous plants, enrich the soil with nitrogen. Trampling by animals (especially around the infrastructures such as drinking troughs and pens) also disturbs vegetation succession [33] and compacts the soils, thereby reducing its infiltration capacity.[146] In dry pine groves (annual rainfall 650 mm), avoid grazing for 20 months after the fire because bryophyte vegetation does not reach its maximum cover until 15 months after the fire, superior vegetation until 20 months after the fire, and erosion only reaches nil 21 to 25 months after the fire.[33] However, these periods can be shortened or lengthened according to how exposed the site is, as in shady spots vegetation regenerates faster [91] and the soil is more structured.[146]

2. REDUCTION OF SOIL EROSION

2.1 Pine forests

2.1 a Whole-tree harvesting

General.

2.1 b Stem-only harvesting/ wood-chopping

General.

2.1 c No harvesting

Making hollows in the soil for when the dead pines fall down should not cause erosion because the trees start to fall after the second winter after the fire when the resprouting and germinating plants of the understory have already started to cover the soil.

2.1 d Optimum time for logging

☞ **BEST.** When a large proportion of the canopy is charred, delay logging until after the aciculas have fallen 12 to 15 weeks after the fire (sometimes more).[145] They will protect the soil from erosion and return some of the nutrients to it.[155] These procedures cannot be applied if the consumed fraction of the canopy is high.

2.1 e Location of logging sites

General.

2.1 f Logging intensity

General

2.1 g Clearing

General.

2.1 h Site preparation

☞ **BEST.** When planting trees after fire, small individual hollows should be made rather than ploughing.

On steep slopes (> 30%) and soft soil, use the pine stems to create erosion barriers, placed parallel to the contour lines that retain the eroded soil [49] (see the explanation in file "7.2 Erosion control procedures").

☞ **AVOID.** Avoid deep ploughing, This can cause soil loss in pine plantations four times higher than post-fire erosion,[145] especially on slopes of more than 15%. [144] During ploughing, make the hollows parallel to the contour lines. Mulch should be applied at the same time as ploughing. This can be mulch made from a compost of the chipped or chopped woody debris from the salvage logging, or a hydro-mulch.

2.1 i Climate conditions

General.

2.1 j Sloping land

General.

2.1 k Specific tasks

General.

2.1 l Silvopasteral benefits

General.

2. REDUCTION OF SOIL EROSION

2.2 Eucalyptus plantations

2.2 a Whole-tree harvesting

General.

2.2 b Stem-only harvesting/ wood-chopping

General.

2.2 c No harvesting

General.

2.2 d Optimum time for logging

General.

2.2 e Location of logging sites

General.

2.2 fLogging intensity

General.

2.2 g Clearing

General.

2.2 h Site preparation

In eucalyptus plantations where the trees were planted by ploughing rather than in hollows, the amount of sediment generated is four times higher and the surface runoff two or three times greater up to four years after the fire. Consequently, in the same environmental conditions, in forests like these soil recovery is slower than in natural forests.[166]

☞ **BEST.** When planting trees after fire, small individual hollows should be made rather than ploughing.

On steep slopes (> 30%) and soft soil, use the pine stems to create erosion barriers, placed parallel to the contour lines that retain the eroded soil [49] (see the explanation in file 7.2 Erosion control procedures).

☞ **AVOID.** Avoid deep ploughing, This can cause soil loss in pine plantations four times higher than post-fire erosion,[145] especially on slopes of more than 15%. [144] During ploughing, make the hollows parallel to the contour lines. Mulch should be applied at the same time as ploughing. This can be mulch made from a compost of the chipped or chopped woody debris from the salvage logging, or a hydro-mulch.

2.2 i Climate conditions

General.

2.2 j Sloping land

General.

2.2 k Specific tasks

☞ **BEST.** The debris from eucalyptus logging, which is mainly comprised of bark, is important to reduce erosion and return some of the nutrients to the soil.[155] Uniformly scattered, the level of erosion will be similar to that of a burned plantation where no logging has taken place, and beneath the threshold that is considered the limit: 1 ton of soil lost per hectare per year. To maximise these benefits, the salvage logging should be carried out as soon as possible so that the debris can be disposed of more quickly. Uniformly scatter at least 2.6 tons of debris per hectare in the burned area (which should be about 5% of the total debris generated),[67, 145] covering 50% of the soil; this way, reductions in erosion of up to 86% can be achieved. Reductions of up to 96% can be achieved by applying 8 tons of debris per hectare, covering 79% of the soil.[67] The debris is more effective if the strips of bark are placed perpendicular to the slope, thus acting as small dams for the sediments.[155]

Not all the debris needs to be scattered, which also reduces the risk of subsequent fires. Furthermore, the fact that this debris is uniformly scattered over the site will make it easier for it to mould itself with the earth with the first rains. As it is in contact with the soil it will stay humid, thus reducing the danger of a subsequent fire.[145]

☞ **AVOID.** Neither pile up the debris from the salvage logging in faggots, nor burn it. These practices cause more erosion than on a burned site with no intervention.[144]

2.2 l Silvopasteral benefits

General.

3. PRESERVATION OF SOIL FERTILITY

3.0 General conditions

3.0 a Whole-tree harvesting

☞ **BEST.** Leave a mosaic of logged and unlogged areas, which will regenerate naturally and may help adjacent logged areas to regenerate.[56] Young conifers contain a higher concentration of nutrients (N, P, K, Ca and Mg) in their stem and branches than mature conifers. The mature conifers should be prioritised in the salvage logging and the youngest trees left in the burned areas so that less nutrients are exported. Furthermore, a greater concentration of nutrients in the timber reduces the combustion quality of the wood chip as it creates less ash.[26]

Preserve as much of the ash, burned debris and leaf litter as possible, as these help retain rainwater.[144] In pine stands, a covering of dead needles seems to be more efficient at preventing erosion than a covering of branches without needles.[155] Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space them out as far apart as possible.[128] Leave clumps of snags in the areas most susceptible to erosion.

☞ **MEDIUM.** The debris from conifer logging provides the soil with more carbon dioxide and nitrogen than planifolium debris.[56] Thus, in mixed forests where whole-tree harvesting has taken place, it is preferable to leave conifer debris on the ground than planifolium debris.

☞ **AVOID.** Avoid whole-tree harvesting across the entire burned area. Do not allow the movement of vehicles with chains.[161]

3.0 b Stem-only harvesting/ wood-chopping

☞ **BEST.** Leave a mosaic of logged and unlogged areas, which will regenerate naturally and may help adjacent logged areas to regenerate.[56] Young conifers contain a higher concentration of nutrients (N, P, K, Ca and Mg) in their stem and branches than mature conifers. The mature conifers should be prioritised in the salvage logging and the youngest trees left in the burned areas so that less nutrients are exported. Furthermore, a greater concentration of nutrients in the timber reduces the combustion quality of the wood chip as it creates less ash.[26]

Fell the trees closest to the roads first, ensuring that they fall crossways to the trail and that the debris from the debranching and chopping stays where it is to lessen the negative effect of circulating agricultural tractors and skidders on the soil.[128] Leave tress in clumps in the areas most susceptible to erosion.

Preserve as much of the ash, burned debris and leaf litter as possible, as these help retain rainwater.[144] In pine stands, a covering of dead needles seems to be more efficient at preventing erosion than a covering of branches without needles. Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space them out as far apart as possible.[128] Leave clumps of snags in the areas most susceptible to erosion.

☞ **MEDIUM.** The debris from conifer logging provides the soil with more carbon dioxide and nitrogen than planifolium debris.[56] Thus, in mixed forests where whole-tree harvesting has taken place, it is preferable to leave conifer debris on the ground than planifolium debris.

☞ **AVOID.** Avoid whole-tree harvesting across the entire burned area. Do not allow the movement of vehicles with chains.[161]

3.0 c No harvesting

☞ **BEST.** To accelerate the incorporation of the nutrients from the dead stems and branches, fell the trees, cut off the branches and chop them up to increase the surface area of the timber in contact with the soil, if possible covering more than 45% of the surface area.[88] Proceed with manual logging to avoid the impact of the machinery on the soil. Prioritise cutting or chipping the branches and stems with a smaller diameter because in the case of pines, the thickest trunks decompose more quickly than the thinner ones.[96]

Where there is risk of erosion, this timber can be chipped and scattered over the burned area as mulch. This chipped debris can accelerate the incorporation of nutrients into the soil, but it decreases the protection afforded to germinating plants.

3.0 d Optimum time for logging

☞ **BEST.** Wait at least a year before entering the forest with machinery to give the plants the chance to germinate, as it is during the first year after the fire that the soil is most sensitive.[56] Logging before one year must be done manually. This delay does not completely neutralise the impact of the possible loss of fertility, but it does help to mitigate the effects.[56]

☞ **MEDIUM.** Wait the time required for the dead or charred leaves and needles to fall from the tree, as they are an important source of nutrients.[155] The resulting leaf litter provides the soil with nutrients and protects it from erosion.

☞ **AVOID.** Avoid beginning forestry work soon after fire.

3.0 e Location of logging sites

☞ **BEST.** The loss of nutrients is much greater in shallow soil than in deep soil.[154] Plan the operation so that the areas with shallow soils are the ones that remain unlogged or where the salvage logging will be carried out later. Whole-stem harvesting should also be done on shallow soil (as opposed to whole-tree harvesting, which is only recommended where the soil is deep).

3.0 f Logging intensity

Lower logging intensities means less loss of soil fertility.

3.0 g Clearing

☞ **BEST.** Reduce the distance the timber is dragged or semi-dragged to the minimum. Clear the forest of the completely suspended wood using a self-loading trailer or an agricultural tractor, or packaged and suspended from a winch (for the chipped wood).[128] Prioritise the use of vehicles with caterpillar tracks. Restrict machinery traffic to the roads and space them out as far apart as possible. If the density of marked roads is low and there is excessive circulation of vehicles along them, this could damage the soil. [128]

Do a preliminary survey and, where necessary, mark the clearing roads and accurately locate the points where the timber will be accumulated to minimise the dragging distances inside the stand being harvested.[119]

Clearing timber with channels is recommended if the wood is to be used as firewood.[128]

For whole-tree harvesting or chopped-wood harvesting, the harvesting debris (mainly the branches) can have uses other than preventing erosion (see files "1. Plant cover regeneration" and “5. Conservation of vertebrate fauna”). Where the whole-tree harvesting is done manually, cut some of the branches before clearing to leave them *in situ* for the same purposes.

☞ **MEDIUM.** When clearing the area by semi-hauling with a skidder, the vehicle must get as close as possible to the felled trees so that they are completely dragged for the shortest possible distance. Do not drag the packs of chipped timber and excessively heavy loads.[128]

☞ **AVOID.** Avoid hauling the logs with an agricultural tractor or a skidder.[128] Compacted soil can impede seed germination, so avoid circulating with machinery on clayey soil when it is wet, as it is more easily compacted, and to a lesser extent, on dry and sandy or clayey soil.[128]

FIGURE 8. Compaction (a) and ruts (b) caused by machinery passing. **Images:** P. Pons.

3.0 h Site preparation

☞ **BEST.** When reforesting, prioritise planting the trees in hollow. Where the land is not very fertile, or the fire has caused a loss of fertility, a compost made of one third mud from the purification system, one third pine bark and one third green vegetation debris (composted for 30 days at 75 °C) can be applied at a quantity of 20 kg per 1 m^3 hollow mixed with the earth in the hollow, or scattered uniformly at an amount of 50 tons of humid compost per hectare. This technique restores soil fertility, improves vegetation nutrition, increases the apical and radial growth of saplings, and increases survival during periods of hydric stress,[73] without causing problems of eutrophication or contributing heavy metals.[24,74] Dispersing 50 tons of humid compost per hectare is more beneficial to woody species than to herbaceous species, which become squashed, creating a mulch where the seeds can germinate and the roots can propagate.[75] Applying quantities of compost that exceed these amounts is not recommended.[24,74,75]

☞ **AVOID.** Avoid deeply ploughing the land as this action increases erosion immediately after the fire beyond the natural levels of the soil.[144]

3.0 i Climate conditions

☞ **AVOID.** Avoid carrying out mechanised tasks on very rainy days when the surface runoff on the soil where the machinery is circulating can be high,[128] and on windy days when the wind can blow away the ash disturbed by the machinery.

During the first year after a moderate or severe fire, do not circulate with machinery in the forest when the soil is excessively humid, frozen or snow-covered, because this causes deterioration in its structure.[144]

3.0 j Sloping land

No information.

3.0 k Specific tasks

No information.

3.0 l Silvopasteral benefits

☞ **AVOID.** Avoid allowing animals to graze on the site in the months following the fire, as this can considerably reduce the abundance of grass and scrub species, which are highly digestible and attractive to herbivores, but whose roots retain rainwater and stabilise and structure the soil and, in the case of leguminous plants, enrich the soil with nitrogen. Trampling by animals (especially around the infrastructures such as drinking troughs and pens) also disturbs vegetation succession [33] and compacts the soils, thereby reducing its infiltration capacity.[146] In dry pine groves (annual rainfall 650 mm), avoid grazing for 20 months after the fire because bryophyte vegetation does not reach its maximum cover until 15 months after the fire, superior vegetation until 20 months after the fire, and erosion only reaches nil 21 to 25 months after the fire.[33] However, these periods can be shortened or lengthened according to how exposed the site is, as in shady spots vegetation regenerates faster [91] and the soil is more structured.[146]

3. PRESERVATION OF SOIL FERTILITY

3.1 Eucalyptus plantations

3.1 a Whole-tree harvesting

General.

3.1 b Stem-only harvesting/ wood-chopping

General.

3.1 c No harvesting

General.

3.1 d Optimum time for logging

General.

3.1 e Location of logging sites

General.

3.1 f Logging intensity

General.

3.1 g Clearing

General.

3.1 h Site preparation

☞ **BEST.** When planting trees after fire, small individual hollows should be made rather than ploughing.

☞ **AVOID.** Avoid deep ploughing, This can cause soil loss in pine plantations four times higher than post-fire erosion,[145] especially on slopes of more than 15%.[144] During ploughing, make the hollows parallel to the contour lines. Mulch should be applied at the same time as ploughing. This can be mulch made from a compost of the chipped or chopped woody debris from the salvage logging, or a hydro-mulch.

3.1 i Climate conditions

General.

3.1 j Sloping land

No information.

3.1 k Specific tasks

☞ **BEST.** The debris from eucalyptus logging, which is mainly comprised of bark, is important to reduce erosion and return some of the nutrients to the soil.[155] Uniformly scattered, the level of erosion will be similar to that of a burned plantation where no logging has taken place, and beneath the threshold that is considered the limit: 1 ton of soil lost per hectare per year. To maximise these benefits, the salvage logging should be carried out as soon as possible. Uniformly scatter at least 0.5 kg/m^2 (5 t/ha) (which should be about 10% of the total debris generated).[145] The debris is more effective if the strips of bark are placed perpendicular to the slope, thus acting as small dams for the sediments.[155]

Not all the debris needs to be scattered, which also reduces the risk of subsequent fires. Furthermore, the fact that this debris is uniformly scattered over the site will make it easier for it to mould itself with the earth with the first rainfall. As it is in contact with the soil it will stay humid, thus reducing the danger of a subsequent fire.[145]

☞ **AVOID.** Do not stack the debris in fagots or burn them. These practices cause more erosion than that of a burned soil without any intervention.[145]

3.1 l Silvopasteral benefits

General.

4. CONSERVATION OF INVERTEBRATE FAUNA

4.1 Soil and litter fauna

4.1 a Whole-tree harvesting

☞ **BEST.** This is the worst harvesting system for most groups of invertebrates as it creates a more homogenous environment than the one left by the fire.[14,18] The effects of this lack of heterogeneity is especially apparent in terms of the diversity of anthropods found in the soil, even decades after salvage logging has taken place.[18]

In the stands made up of germinators (pines), preserve the live and dying trees as their roots can feed the underground fauna.[120]

If this is the preferred harvesting system, some areas must be left unlogged (see recommendation "4.1 e Locating the salvage logging").

4.1 b Stem-only harvesting/ wood-chopping

☞ **BEST.** This seems to be the best harvesting system for some invertebrates such as gastropods, hymenopterans and coleoptera, as the branches and other debris from the salvage logging are left scattered on the site and this woody debris creates a more heterogenous habitat, protects the soil from solar radiation and extremes of temperature, and maintains a higher degree of humidity. This system seems to be better than no harvesting at all because then the branches stay suspended in the trees and do not afford the soil as much protection.[14,69,95]

4.1 c No harvesting

☞ **BEST.** Doing no salvage logging is the best option to conserve the spider communities,[117] but it is not as beneficial to gastropods, hymenopterans and coleoptera.

☞ **WORST.** For some invertebrates such as gastropods and hymenopterans, this type of harvesting is not the most recommended as the branches stay at the height of the canopies generating a more homogenous habitat and affording the soil less effective protection from solar radiation and extremes of temperature, and not allowing such a high degree of humidity to be maintained as when the branches are scattered on the ground. If this is the preferred system, ideally the stems and branches should be cut and the biomass should be left scattered throughout the logging strip.[14,95]

4.1 d Optimum time for logging

☞ **BEST.** In fires of low and moderate severity, organic material can be contributed to the soil if sufficient time passes to allow the leaves and aciculas from the charred canopy to fall before carrying out the salvage logging.

4.1 e Location of logging sites

☞ **BEST.** Carry out aggregated retention combined with dispersed retention (see files "0.2 Burned Wood retention as a mitigation measure" and "0.3 Standing tree preservation areas").

If there are no isolated snags, then leave some live ones.[116] Ensure that the areas where woody debris is retained measure at least 200 m at their narrowest point. Carry out partial logging around the small woods to prevent there being a big contrast between the logged and the unlogged areas.[76]

It is important to conserve both the unburned patches of vegetation and leaf litter (which may only measure a few square metres) in order not to disturb the soil, and to serve as a habitat for forest species. [69] Conserve any dead trees there may be on these patches.[116]

In masses of non-serotinous pines where there are small stands and groups of resprouting plants (either trees or scrub), conserving them is recommended as this enables the vegetation cover to regenerate more quickly.[171]

Machinery traffic should be restricted to the roads, which should be as spaced out as far apart as possible.[128]

Take even greater precautionary measures in the driest areas as the reestablishment of anthropods such as spiders is slower there.[106]

☞ **MEDIUM.** Only carry out aggregated retention. Make sure the retention areas measure at least 100 m at their narrowest point.[76]

As the impact of salvage logging is greater in conifer stands (they take longer to germinate) than in panifolium stands (which resprout), prioritise aggregated retention in resinous forests.[116]

☞ **WORST.** Only retain isolated trees, especially trees that are alive or dying. If possible, leave clumps of unfelled trees covering 0.5 ha or more [116] or leave groups comprised of 10 to 20 trees.[69]

4.1 f Logging intensity

The more intense the salvage logging operation, the greater its effects on communities of coleoptera. The most recommended practices are where less volume of timber is collected.[69] After salvage logging, the volume of dead wood should be similar to the amount found naturally in an unburned wood (where no timber harvesting has taken place).[126] Use the amount of dead wood found in Spanish forests as a benchmark (IFN3 and IFN4), but bear in mind that in forests where harvesting has taken place, this volume can be two to five times lower than in forests without harvesting [83]:

☞ **BEST.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average multiplied by five):

Deciduous oak, holm oak and Aleppo pine groves: 40%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 30%

Black pine groves and eucalyptus plantations: 20%

☞ **MEDIUM.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average multiplied by two):

Deciduous oak, holm oak and Aleppo pine groves: 16%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 12%

Black pine groves and eucalyptus plantations: 8%

☞ **WORST.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average):

Deciduous oak, holm oak and Aleppo pine groves: 8%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 6%

Black pine groves and eucalyptus plantations: 4%

4.1 g Clearing

No information.

4.1 h Site preparation

☞ **BEST.** Avoid ploughing the land. It has been observed that in stands with stem-only harvesting the last plough before planting is detrimental to gastropods to the point where the advantages of this harvesting system are annulled, making this the worst scenario and even more damaging than not harvesting the dead wood.[14] The same effect is observed for hymenopterans, if not as severely.[95]

4.1 i Climate conditions

No information.

4.1 j Sloping land

No information.

4.1 k Specific tasks

☞ **BEST.** In conifer stands, conserve any resprouting species there may be in the understory as this will supply the soil with organic material more quickly and their roots can provide sustenance for the hypogeal invertebrates that feed off them.[120] See the recommendations in file "1. Plant cover regeneration" to accelerate recovery.[139]

In small strawberry tree woods, the living-stump selection of does not alter the structure or the composition of the ant communities found there.[121]

4.1 l Silvopasteral benefits

☞ **BEST.** Avoid allowing animals to graze on the site in the months following the fire, as this can considerably reduce the abundance of grass and scrub species, which are highly digestible and attractive to herbivores, but which offer the invertebrates in the soil protection from solar radiation, extremes of temperature and dehydration.[139]

☞ **MEDIUM.** If you allow grazing, prioritise sheep and goats and avoid cows and horses who trample the soil more with their greater weight. Soil computation reduces the amount and size of pores, leading to an alteration in the microbial communities and nematodes found there, thus negatively affecting the trophic chain of the anthropods.[106]

4. CONSERVATION OF INVERTEBRATE FAUNA

4.2 Saproxylic invertebrates and control of wood-boring insects

4.2 a Whole-tree harvesting

SAPROXYLIC INVERTEBRATES

☞ **BEST.** This is the worst harvesting system for most of the groups of invertebrates as most of the dead wood is exported. Woody debris of different diameters must be left on the logging strip, as stems with different diameters host different saproxylic communities.[96] Because the quantity of dead wood (volume per unit of surface area) and its different diameters is more important for conserving the communities of saproxylic invertebrates than its quality (understood as the degree of composition),[29] some dead stems must be preserved, both standing and felled (see recommendation "4.2 f Logging intensity").

4.2 b Stem-only harvesting/ wood-chopping

SAPROXYLIC INVERTEBRATES

☞ **BEST.** This harvesting system is more favourable to saproxylic invertebrates than whole-tree harvesting as part of the burned wood, the branches, are preserved. However, because the quantity of dead wood (volume per unit of surface area) and its different girths is more important for conserving the communities of saproxylic invertebrates than its quality (understood as the degree of composition),[29] some dead standing and felled stems must also be preserved as this increases the diversity of diameters available for saproxylic species (see recommendation "4.2 f Logging intensity").

4.2 c No harvesting

SAPROXYLIC INVERTEBRATES

☞ **BEST.** Doing no salvage logging is the most suitable option to preserve communities of saproxylic invertebrates. Where trees are felled, ensure that the cut stems are laid in a N-S direction in sunny spots and in an E-W direction in shady spots. Avoid felling all the trees; leave trees with different girths standing to provide structural and decomposition heterogeneity (Eduard Piera, pers. com.).

WOOD-BORING INSECTS

☞ **BEST.** The risk of dead wood left in the forest becoming the focus of infestation for the neighbouring stands is minimal.[60] Only trees weakened by the fire are the focus of plagues of wood-boring insects.[138] Salvage logging the peripheric dying trees is only recommended when there are weakened forest masses near the burned area (for example, due to recurrent episodes of hydric stress). Ideally, monitor the trees and fell them if they show signs of health problems.

4.2 d Optimum time for logging

WOOD-BORING INSECTS

If the decision is made to fell the pines affected by wood-boring insects to prevent them spreading to the rest of the pines that have survived the fire, doing so before the larva finish their subcortical development and emerge as adults or juveniles is difficult as many wood-boring insects complete their life cycle in the space of a few weeks or months. These insects are most active during the spring and the summer. In cold climates, the life cycle is slower, leaving a larger window for carrying out the operation.

4.2 e Location of logging sites

SAPROXYLIC INVERTEBRATES

Inland saproxylic forest species do not proliferate if the remaining groups of trees occupy less than a hectare. As the edge effect is important, when leaving clumps of uncut trees, the speed at which the edge effect will be diminished must be evaluated:

☞ **BEST.** Resproutings (holm oak, deciduous oak and cork oak): clumps measuring ≤ 1 ha can be left. Germinators (pines): leave clumps > 3 ha.

☞ **MEDIUM.** Resproutings (holm oak, deciduous oak and cork oak): clumps measuring ≤ 1 ha can be left. Germinators (pines): leave islands > 1 ha.

☞ **WORST.** Leaving the standing trees scattered.

4.2 f Logging intensity

SAPROXYLIC INVERTEBRATES

The more intense the salvage logging operation, the greater its effects on communities of coleoptera. The most recommended practices are where less volume of timber is collected.[69] After salvage logging, the volume of dead wood should be similar to the amount found naturally in an unburned wood (where no timber harvesting has taken place).[126] Use the amount of dead wood found in Spanish forests as a benchmark (IFN3 and IFN4), but bear in mind that in forests where harvesting has taken place, this volume can be two to five times lower than in forests without harvesting [83]:

☞ **BEST.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average multiplied by five):

Deciduous oak, holm oak and Aleppo pine groves: 40%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 30%

Black pine groves and eucalyptus plantations: 20%

☞ **MEDIUM.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average multiplied by two):

Deciduous oak, holm oak and Aleppo pine groves: 16%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 12%

Black pine groves and eucalyptus plantations: 8%

☞ **WORST.** Conserve the following volumes of burned wood without harvesting (as a percentage of the volume of timber with bark present in the stand before the fire, the Spanish average):

Deciduous oak, holm oak and Aleppo pine groves: 8%

Sparsely wooded pastures, stands of oak sprouts and Scots pine and Monterey pine groves: 6%

Black pine groves and eucalyptus plantations: 4%

The **black pine**, together with the *Abies pinsapo,* are probably the species of Mediterranean conifer on the Iberian peninsula with the greatest diversity of associated saproxylic coleoptera (Eduard Piera, pers. com.). To maintain this diversity, a greater proportion of unharvested dead wood must be left in these stands.

4.2 g Clearing

No information.

4.2 h Site preparation

No information.

4.2 i Climate conditions

No information.

4.2 j Sloping land

No information.

4.2 k Specific tasks

WOOD-BORING INSECTS

If there are signs of the presence of wood-boring insects in the pines weakened by the fire, these can spread to the rest of the pines that have survived the fire, which may cause them to die. Wood-boring insects prefer trees with a smaller diameter and a thinner bark, and they can be found above the height where the flames have charred the stem and on the most severely affected soil.[9]

☞ **BEST.** Do not fell any of the trees weakened by the fire, regardless of whether they show signs of being attacked by wood-boring insects. In the long-term, the delayed death of these trees will provide timber for saproxylic organisms, and they may also produce seeds before they die.

☞ **MEDIUM.** Cut and transport as timber the trees that show signs of being attacked by wood-boring insects. This harvesting must be done as soon as possible to prevent the biological cycle of the insect from completing.

☞ **WORST.** Cut and transport as timber the trees that have signs of attack by wood-boring insects, as well as the live trees that have been weakened by the fire but have no sign of attack by wood-boring insects. This harvesting must be done as soon as possible to prevent the biological cycle of the insect from completing.

☞ **AVOID.** Avoid the indiscriminate salvage logging of all the surviving but affected trees simply because they show signs of the presence of wood-boring insects.

4.2 | Silvopasteral benefits

No information.

5. CONSERVATION OF VERTEBRATE FAUNA

5.1 Birds

5.1 a Whole-tree harvesting

If this harvesting system is employed on a suitable scale it can encourage the diversity of open-habitat birds. [84,134] This harvesting system can be used to favour open-habitat species of birds (provided that the populations are near enough to colonise the burned area) that are threatened on a European scale due to loss of habitat caused by agricultural intensification and the abandonment of marginal agricultural and herding areas. However, this harvesting system is not suitable for everywhere, and some of the snags must be retained.[134] Whether or not to apply this harvesting system to preserve the habitat for open-environment species should be assessed on a regional level because it is the most detrimental harvesting system for most species of animals.

5.1 b Stem-only harvesting/ wood-chopping

☞ **BEST.** This harvesting system leads to an increase in the number of frugivorous birds in the winter if the branches have been left in piles or faggots. Seed-dispersing birds that select the lowest strata of vegetation (such as warblers and robins) use these piles and faggots more than the other structures in this habitat (earth, bush strata, snags and live trees in the burned area), and the seeds in their excrement find a more suitable microhabitat there to germinate (see file "1. Plant cover regeneration"). It is recommended to make at least twenty piles of branches per hectare to increase the chance that the burned area will accommodate a greater wealth and abundance of frugivorous birds species.[133] It is best to use all the burned trees, fixing the debranched stems to the ground with stakes (if they are correctly fixed to the soil they can be used as an erosion control measure, see file "7.2 Erosion control procedures") and piling the branches on top of them to reach heights of between 0.5 and 1 m. Using only branches, however, is just as effective.[133]

☞ **MEDIUM.** In stem-only harvesting where the branches are left scattered on the ground, the wealth in species and the abundance of individuals are somewhere in-between the unharvested stands and the whole-tree harvested stands.[21]

5.1 c No harvesting

☞ **BEST.** Some of the species of birds found in closed forest habitats (such as tits and jays) can still be present in the burned areas where no salvage logging has taken place [21,84] until the burned trees fall down. In these environments, these species continue to play their role in controlling insect populations and dispersing acorns.[21]

☞ **MEDIUM.** Felling some of the trees and leaving them on the ground has a similar result to not intervening in the burned site at all, although the wealth and abundance of forest species are slightly lower.[21] On the other hand, certain species of understory can benefit.

5.1 d Optimum time for logging

☞ **BEST.** Avoid carrying out forestry work between 1 May and 30 June. This date can be brought forward for warmer areas, and delayed for colder areas and in the mountains.

Avoid carrying out forestry work during the breeding season of sensitive species of large birds and mammals in areas designated by the environmental services of each autonomous community. Sensitive species are understood to be those considered as threatened and those negatively affected by noise and the presence of people and machinery near their breeding territory.

☞ **MEDIUM.** Avoid carrying out forestry work between 15 April and 15 June. This date can be brought forward for warmer areas, and delayed for colder areas and in the mountains.

Avoid carrying out forestry work during the breeding season of sensitive species of large birds and mammals in areas designated by the environmental services of each autonomous community. By sensitive species is understood those considered as threatened and those negatively affected by noise and the presence of people and machinery near their breeding territory.

☞ **WORST.** Having no forestry task calendar makes it difficult to coordinate with environmental services agents during the breeding seasons of the most sensitive species of large birds and mammals.

5.1 e Location of logging sites

☞ **BEST.** The felled dead trees on the logging strip should be left mostly in groups, and some scattered snags should also be conserved.[63] This mosaic-like pattern means that a more closed environment can be preserved for forest birds, while at the same time providing more open areas for open-habitat birds. The scattered snags are not detrimental to species that require open environments, and they also serve for roosting.[21,64,129] Groups of unfelled trees can be left in areas that are more prone to erosion,[134] according to the recommendations set out in "0.3 Standing tree preservation areas".

☞ **WORST.** Having dead trees left distributed uniformly on the logging strip does not create an environment that attracts forest birds, even if 10% of the trees are preserved and the branches left on the ground.[22]

5.1 f Logging intensity

☞ **BEST.** Three hundred burned snags should be left per hectare to encourage species of birds that depend on snags. They should measure at least 22.5 cm in diameter and 2 m in height.[63] If this is not possible, a wide distribution of the remaining trees should be planned, prioritising the larger trees.[134]

☞ **MEDIUM.** Two hundred burned snags should be left per hectare to encourage species of birds that depend on snags. They should measure at least 22.5 cm in diameter and 2 m in height.[63]

☞ **WORST.** One hundred burned snags should be left per hectare to encourage species of birds that depend on snags. They should measure at least 22.5 cm in diameter and 2 m in height.[63]

5.1 g Clearing

No information.

5.1 h Site preparation

No information.

5.1 i Climate conditions

No information.

5.1 j Sloping land

No information.

5.1 k Specific tasks

Where the aim is to use the salvage logging operation to create an open habitat suitable for birds (for example, the partridge and the Bonelli's eagle), other measures apart from the silvopastoral harvestings can be taken, including [129] :

Ecological cultivation of cereals (wheat, barley, oats and rye) or pulses (lupin beans and sainfoin).

Installing drinking troughs near the scrub and puddles that collect rainwater.

Clearing operations in the dense, continuous scrub in an elongated shape and measuring less than 1 ha.

Post-fire thinning of the pine saplings in the young pine stands, at least 1,000 trees/ha, and the selection of deciduous oak and holm oak stumps, at least 100 sprouts/ha.

Installing artificial burrows for rabbits made of pallets, tubes or rocks, in places with little vegetation cover and soil that is too hard to be excavated.

Making stump selections in small woods of strawberry trees improves the quality of the fruit produced (greater dry weight, more seeds per fruit and a lower rate of seed abortion) while maintaining the quantity.[121]

5.1 l Silvopasteral benefits

Extensive grazing is the most effective, susstainable way to maintain plots of open habitats that will be used by birds that feed in these environments.[129] Nonetheless, fence in the pastures during the first years after the fire to reduce problems of soil erosion (see file "2. Reduction of soil erosion") and to encourage the growth of a protective layer of vegetation cover over the soil (see file "1. Plant cover regeneration").

5. CONSERVATION OF VERTEBRATE FAUNA

5.2 Mammals

5.2 a Whole-tree harvesting

RABBITS

This harvesting system can facilitate the mobility and availability of food, but it has the disadvantage of not providing any shelter.[130]

RODENTS

This is the worst harvesting system for rodents, both those that inhabit open areas (who cannot find shelter there) and those that prefer covered habitats.[58]

UNGULATES

This harvesting system is the one that provides herbivore ungulates with the best access to seedlings, which could hamper vegetation regeneration.

5.2 b Stem-only harvesting/ wood-chopping

RABBITS

☞ **BEST.** This can be the best harvesting system for rabbits if the branches are piled up to create shelter. If there is little vegetation or the soil is too hard to be excavated, these piles also provide useful spots for breeding. The open spaces between the piles of branches serve as a place to feed and facilitates their mobility.[129]

☞ **MEDIUM.** If the branches are left scattered they do not provide such safe shelter as when they are piled up, and they reduce the amount of open space where the rabbits can feed and move around easily.

☞ **WORST.** If the branches are to be taken away (leaving the rabbits without any shelter), this should be done at the same time as the trees are felled.[130]

RODENTS

Rodents that frequent open areas but also need shelter benefit from this harvesting system.[70] The branches are best left in piles or faggots, which can be done either manually or mechanically.[150] For rodents that inhabit open areas, the best practice is to leave the burned stems on the ground, which the rodents will use for moving around, orientating themselves, feeding, breeding and shelter. If the stems cannot be left, ensure that the biggest branches are left on the ground.[58]

UNGULATES

This harvesting system can make it difficult for herbivore ungulates to access the seedlings of the regenerating vegetation. Its effectiveness in decreasing the consumption of acorns by wild boar has been demonstrated.[77]

5.2 c No harvesting

RABBITS

No harvesting should provide rabbits with the same benefits as whole-tree harvesting as no branches are thereby left on the ground to reduce their mobility and the availability of food. The amount of shelter will gradually increase over time as the dead trees and their branches fall.

RODENTS

Populations of rodents recover better if after the fire there is no intervention rather than stem-only harvesting leaving the branches on site, or whole-tree harvesting. This way, the rodent communities recover in just 1 to 2 years. Of the two harvesting systems (stem-only or whole-tree), either can be the most beneficial depending on the habitat preference (open or closed) of the species of rodent in question.[62]

UNGULATES

Leaving the trees to fall naturally is recommended to hamper ungulates' access to seedlings.[42]

5.2 d Optimum time for logging

☞ **BEST.** Avoid carrying out forestry work between 1 May and 30 June. This date can be brought forward for warmer areas, and delayed for colder areas and in the mountains.

Avoid carrying out forestry work during the breeding season of sensitive species of large birds and mammals in areas designated by the environmental services of each autonomous community. Sensitive species are understood to be those considered as threatened and those negatively affected by noise and the presence of people and machinery near their breeding territory.

☞ **MEDIUM.** Avoid carrying out forestry work between 15 April and 15 June. This date can be brought forward for warmer areas, and delayed for colder areas and in the mountains.

Avoid carrying out forestry work during the breeding season of sensitive species of large birds and mammals in areas designated by the environmental services of each autonomous community. By sensitive species is understood those considered as threatened and those negatively affected by noise and the presence of people and machinery near their breeding territory.

☞ **WORST.** Having no forestry task calendar makes it difficult to coordinate with environmental services agents during the breeding seasons of the most sensitive species of large birds and mammals.

5.2 e Location of logging sites

Conserve the unburned areas intact, including any dead and charred trees in the interior. These areas will serve as the nucleus for the colonisation of species that have survived the fire.[8]

RABBITS

The hardness of the soil is not a consideration when deciding where to do the salvage logging, provided there is enough vegetation to provide the rabbits with shelter and a place for breeding.[130]

5.2 f Logging intensity

No information.

5.2 g Clearing

No information.

5.2 h Site preparation

No information.

5.2 i Climate conditions

No information.

5.2 j Sloping land

No information.

5.2 k Specific tasks

Making stump selections in small woods of strawberry trees improves the quality of the fruit produced (greater dry weight, more seeds per fruit and a lower rate of seed abortion) while maintaining the quantity.[121]

5.2 l Silvopasteral benefits

No information.

5. CONSERVATION OF VERTEBRATE FAUNA

5.3 Herpetofauna

5.3 a Whole-tree harvesting

REPTILES

Increased light on the soil is advantageous to reptiles. However, if after a salvage logging operation there is a shortage of shelter in the burned area (such as rocks larger than 30 cm x 30 cm or drystone walls), it is recommended to create some. Leave the trees standing and the logs on the ground (the latter are used as a place to bask and as a shelter). A suitable refuge can be made with two logs measuring 1.2 m long and at least 20 cm in diameter, placed adjacent to each other longitudinally to create ≥ 6 shelters/ha. The exact number will depend on the abundance of other natural refuges.[92,141].

5.3 b Stem-only harvesting/ wood-chopping

REPTILES

Increased light on the soil is advantageous to reptiles. However, if after a salvage logging operation there is a shortage of shelter in the burned area (such as rocks larger than 30 cm x 30 cm or drystone walls), it is recommended to create some. Leave the trees standing, leave the logs on the ground (used as a place to bask and as a shelter), and pile up the branches (which will also serve as refuges). A suitable refuge can be made with two logs measuring 1.2 m long and at least 20 cm in diameter, placed adjacent to each other longitudinally to create ≥ 6 shelters/ha. The exact number will depend on the abundance of other natural refuges.[92,141]

5.3 c No harvesting

REPTILES

Increased light on the soil is advantageous to reptiles. However, if after a salvage logging operation there is a shortage of shelter in the burned area (such as rocks larger than 30 cm x 30 cm or drystone walls), it is recommended to create some. Leave the trees standing, leave the logs on the ground (used as a place to bask and as a shelter), and pile up the branches (which will also serve as refuges). A suitable refuge can be made with two logs measuring 1.2 m long and at least 20 cm in diameter, placed adjacent to each other longitudinally to create ≥ 6 shelters/ha. The exact number will depend on the abundance of other natural refuges.[92,141]

AMPHIBIANS

Not harvesting the site is the best option for amphibians as it provides them with shelter from excessive heat.[148] To maximise these benefits, the trees can be felled (in particular the biggest ones) and left on the ground where they will become refuges, retaining a certain amount of humidity near the soil

5.3 d Optimum time for logging

Avoid carrying out forestry work during the breeding season of sensitive species of large birds and mammals in areas designated by the environmental services of each autonomous community. By sensitive species is understood those considered as threatened and those negatively affected by noise and the presence of people and machinery near their breeding territory.

5.3 e Location of logging sites

Conserve the unburned areas intact, including any dead and charred trees in the interior. These areas will serve as the nucleus for the colonisation of species that have survived the fire.[8]

5.3 f Logging intensity

No information.

5.3 g Clearing

No information.

5.3 h Site preparation

No information.

5.3 i Climate conditions

No information.

5.3 j Sloping land

No information.

5.3 k Specific tasks

REPTILES

If after a salvage logging operation there are few large rocks (more than 30 cm x 30 cm thick), and the idea is not to leave stems on the ground, then artificial refuges can be made from either rocks or cement at a rate of ≥ 6 shelters/ha. Avoid making metal refuges as these become too hot during the day and the conserve little heat during the night.[92]

5.3 l Silvopasteral benefits

No information.

6. REDUCTION OF SUBSEQUENT FIRE RISK

6.0 General conditions

6.0 a Whole-tree harvesting

Whole-tree harvesting is the most effective method to reduce the amount of fuel available for subsequent fires. The little dead wood debris left on the logging strip does not require any subsequent treatment.[127]

6.0 b Stem-only harvesting/ wood-chopping

The disadvantage of stem-only harvesting is that the branches and the canopies are left on the ground, immediately increasing the amount of fine woody fuel.[36] Furthermore, pines take longer to decompose than logs due to their reduced diameter.[96] This debris can set on fire and propagate the flames very quickly, but if their mass is weak the fire will not be very intense.[17]

If the branches are not to be used to create piles for the benefit of the flora and fauna, or to construct erosion control measures, see recommendation “6.0 k Specific tasks” to know the recommended process for this debris.

6.0 c No harvesting

Not harvesting the site avoids the problem of immediately contributing to the amount of surface fuel, but in the mid-term (from the third year after the fire), woody debris that still has the capacity to burn begins to accumulate on the ground both in the form of stems and branches, and in greater amounts than those observed in forests where no harvesting has taken place for a long time.[71,127] Therefore, felling the trees and simply leaving them in the burned area is of no benefit regarding future fires, as they will fall down naturally anyway. Felling the trees and leaving them *in situ* must be done for other ends, such as to avoid future damage to saplings that become established after the fire due to the stems and canopies falling, or to benefit the fauna in closed environments.

6.0 d Optimum time for logging

No information.

6.0 e Location of logging sites

AREAS FOR PROMOTING FOREST MANAGEMENT

The Areas for Promoting Forest Management (APFM) are areas where strategic actions are implemented to intervene in a fire's maximum capacity to propagate, thus indirectly generating a larger window of opportunity for control. To reduce the risk of a second fire, it is recommended that the post-fire action should be whole-tree harvesting or, where stem-only harvesting is carried out, the woody debris is eliminated by chipping/chopping *in situ* or on the trail. Leaving the woody debris spread on the ground in sections is not recommended.[11] For the different types of fires that occur in Catalonia, the APFMs are:

Bottom of ravines and the intersection of ravines, in areas affected by topographic fires.

High parts of south-, south-west and west-facing crests, in areas affected by convective fires with or without wind.

Recessed and wind protected areas, in areas affected by wind-driven fires.

Intersections of crests, in areas affected by wind-driven fires.

Mountain pass, in areas affected by wind-driven fires.

The size of the area to be considered varies depending on specific characteristics, but a minimum width of 60 m can be set as a guideline (for example, at the intersection of a ravine, 30 m from one side of the thalweg line to the other) [11]. Follow the recommendations in file "6.0 k: Specific tasks" for more information on the treatment of woody debris from the salvage logging.

DISTRIBUTION OF STANDING TREES

In case of partial felling, keep standing dead trees (snags) clustered or dispersed seems to influence the timing of his fall, and therefore the surface fuel input will at the same rate.[128] In case of subsequent fire, the clustered arrangement of standing dead trees can create more heterogeneous fires, with more intense areas where there has been retention of standing dead trees, while the dispersed arrangement can create more homogeneous fires, with a lower intensity that of the sites where the standing dead trees have been preserved standing clustered.

6.0 f Logging intensity

☞ **BEST.** In case of partial felling, larger diameter trees should be kept standing. Those trees hold more time upright and therefore will not accumulate surface fuel so quickly. In addition, large trunks are less flammable and spread fire more slowly.[128]

For inland forests in the western United States, in order to reduce the risk of subsequent fire, it is advised not to exceed 45 tons per ha of burned debris in dry and warm forests, and 67 tons per ha in fresh forests or in humid mountain areas. [17]

☞ **MEDIUM.** In case of leaving part or all of the dead wood without chipping in situ, it is advised not to exceed the amounts mentioned below because in case of fire they would generate difficult situations to control:[17]

If you leave up to 11 tons/ha of fine surface fuel (< 7.5 cm in diameter), do not leave more than 56 tons of large-size fuel (> 7,5 cm de diameter).

If you leave up to 22 tons/ha of fine surface fuel (< 7.5 cm in diameter), do not leave more than 33 tons of large-size fuel (> 7.5 cm in diameter).

If you leave up to 33 tons/ha of fine woody fuel (< 7.5 cm in diameter), do not leave more than 11 tons of large-size fuel (> 7.5 cm in diameter).

☞ **WORST.** In case of leaving part or all of the dead wood without chipping in situ, it is advised not to exceed the amounts mentioned below because in case of fire they would generate difficult situations to control:[17]

If you leave up to 11 tons/ha of fine surface fuel (< 7.5 cm in diameter), do not leave more than 90 tons of large-size fuel (> 7,5 cm de diameter).

If you leave up to 22 tons/ha of fine surface fuel (< 7.5 cm in diameter), do not leave more than

56 tons of large-size fuel (> 7.5 cm in diameter).

If you leave up to 33 tons/ha of fine woody fuel (< 7.5 cm in diameter), do not leave more than 33 tons of large-size fuel (> 7.5 cm in diameter).

6.0 g Clearing

No information.

6.0 h Site preparation

STEM-ONLY HARVESTING

If after the fire regeneration is scarce and the decision is made to reforest the stands by means of planting, the soil must be cleared of dead wood debris (if there has not been whole-tree harvesting). The debris can be chipped, chopped [1] or used to create piles or faggots. If these structures cover too large an area, the debris can be burned. The amount of heat generated can be manipulated up to a point by controlling the controlled burns (thus decreasing the damage done to the flora and the soil) and the amount of timber consumed (conserving some for the benefit of the fauna and for erosion control). The negative impacts of this practice include the possibility of the fire getting out of control, the smoke, excessive heat that can alter the soil and the excessive consumption of large debris that could be useful to the fauna.[109]

6.0 i Climate conditions

No information.

6.0 j Sloping land

No information.

6.0 k Specific tasks

STEM-ONLY HARVESTING WITHOUT HARVESTING THE BRANCHES

Chipping or chopping the debris: when the debris is chipped, the wood chips must be scattered uniformly around the logging strip, but the layer must be no thicker than 3 cm to avoid making germination difficult and to ensure that the wood chips are in contact with the soil so that they stay humid, thus reducing their flammability.[1] As the chopped wood can burn more intensely than the wood chips, spreading this heterogeneously throughout the logging strip is recommended to avoid large stretches of easily-burnable material.[1]

Creating piles and faggots: accumulated timber, and especially the fine parts like the branches can be a dangerous fuel load. Avoid accumulations of this timber that form large barriers or continuous lines as these could increase the propagation of a future fire and make extinguishing it more difficult. A large concentration of timber in faggots could create areas with a huge fuel intensity.[1]

Proximity to roads: it is recommended not to leave logging debris stretching from one side of a rural or forest trail to the other. This prohibition is often regulated by the local government, so find out this information.

ARTIFICIAL REGENERATION

If the decision is made to artificially regenerate the site after fire (either by planting or by enrichment), the stands should be guided towards a type of forest that is at less risk of fire, even if a large-scale conversion may be difficult and costly.[170]

SELECTION OF LIVING-STUMPS IN SMALL WOODS OF STRAWBERRY TREES

In small woods of strawberry trees, the living-stump selection enables the fuel continuity to be broken both vertically and horizontally, which could otherwise stay there for a long time. This action also means that resprouts are eliminated early on, as they would only die later anyway, accumulating biomass. A stools selection the following year is recommended.[121]

6.0 l Silvopasteral benefits

Grazing would intervene in the amount of live fuel but not in the amount of burned dead wood, apart from the trampling the cows could do on the dead branches, breaking and compacting it. This trampling, however, would not have a significant impact and would cover a very small area as it is mainly only where paths have been made between grazing areas.[153]

In any case, in the first years after the fire, the regeneration of plant cover and the prevention of soil erosion should be prioritised over reducing fuel loads through grazing (see file "1. Plant cover regeneration" and "2. Reduction of soil erosion"). Once the vegetation cover has recovered, the amount of fine woody fuel can be controlled and decreased by means of grazing goats.

7. PRESERVATION OF THE QUALITY OF RIVER AND RIVERBANK HABITATS

7.1 Riparian forests and water courses

7.1 a Whole-tree harvesting

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

☞ **BEST.** Avoid cutting and taking away both the dead and live trees from riparian habitats.[165]

☞ **MEDIUM.** If partial logging is carried out, leave the largest dead trees as these are more difficult for the river to move and so will stay in the riverine and riparian habitat for longer.[32]

7.1 b Stem-only harvesting/ wood-chopping

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

☞ **BEST.** Avoid cutting and taking away both the dead and live trees from riparian habitats.[165]

☞ **MEDIUM.** If partial logging is carried out, leave the largest dead trees as these are more difficult for the river to move and so will stay in the riverine and riparian habitat for longer.[32]

7.1 c No harvesting

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

☞ **BEST.** No harvesting is the best scenario for conserving the biological and geomorphological quality of the riverine and riparian habitats.[165]

7.1 d Optimum time for logging

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

☞ **BEST.** Avoid salvage logging for the months before and during the egg-laying season of fish and amphibians. During this period, contributing sediment to the water course is detrimental to the development of the eggs.[32]

7.1 e Location of logging sites

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

Leave unlogged (or with very little logging) a strip of riparian forest and the forested area adjacent to perennial or intermittent water courses.[32]

☞ **BEST.** This strip must measure at least 40 m wide.[27]

☞ **MEDIUM.** This strip must measure at least 20 m wide.[27]

☞ **WORST.** This strip should measure at least 10 m wide.[27]

FORESTS (NOT RIPARIAN OR FORESTED AREAS ADJACENT TO TORRENTS)

Leave a strip of uncut burned trees uncut on the perimeter of the burned area and do not allow machinery to circulate there. This can reduce runoff and sediment exportation downriver, and it stops the water and sediments from unburned areas upriver from crossing the burned area and adding to its erosion potential.[27,105]

☞ **BEST.** Leave a strip between 30 and 60 m wide around the entire perimeter of the fire both upriver and downriver, where there will be no harvesting or machinery movement.

☞ **MEDIUM.** Leave a strip between 30 and 60 m wide around the entire perimeter of the fire downriver where there will be no harvesting or machinery movement.

☞ **WORST.** Leave a strip between 30 and 60 m wide around the entire perimeter of the fire downriver where there will be no harvesting or machinery movement, and where only the trees that can be cut and cleared from the logging strip without opening harvesting roads or corridors will be harvested.

7.1 f Logging intensity

RIPARIAN FORESTS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

The impacts on riverine habitats are greater in the strips that are most heavily logged, in the headwaters of the rivers and on courses that flow on gravel beds, which are more easily eroded laterally if the vegetation is cut.[32,122] Salvage logging in riparian habitats is especially detrimental to amphibians.[27]

☞ **BEST.** Retain all the burned trees in the riparian habitats. Fell only those that are at risk of falling on the roads and the infrastructure.

☞ **MEDIUM.** In the riparian habitats, cut only the dead trees that can be cut and cleared from the nearest trail, without opening up clearing roads and corridors. Preserve all the trees at the headwaters of the water courses, including those that have fallen down.

☞ **WORST.** Harvest all the burned riparian trees.

7.1 g Clearing

On the logging strip, follow the recommendations in file “2. Reduction of soil erosion”.

7.1 h Site preparation

On the logging strip, follow the recommendations in file “2. Reduction of soil erosion”.

7.1 i Climate conditions

On the logging strip, follow the recommendations in file “2. Reduction of soil erosion”.

7.1 j Sloping land

On the logging strip, follow the recommendations in file “2. Reduction of soil erosion”.

7.1 k Specific tasks

Salvage logging, both in the burned forests and in the riparian forests affects the aquatic environment and should be compatible with riverine regeneration.[66]

RIPARIAN HABITATS AND AREAS ADJACENT TO WATER COURSES OR TORRENTS

From a hydraulic point of view, dead wood management requires an evaluation of the risks and advantages of the timber nucleuses in the water course. Additionally, the riverine dynamics and the singular water features of the environment under study must be evaluated section by section.[61] From the ecological point of view, in the long term, removing dead wood from riparian habitats means suppressing the only source of sizeable dead wood in that section of the river until the trees regenerate to the size of adult trees.[32,122] Existing riparian habitats can also capture the dead wood floating on the river.[38]

Debris dams for retaining sediment in the headwaters are only effective while they are filling up and during rainy episodes that are not extreme.[49,108,165] Furthermore, they create a barrier for upriver fish colonisation.[165] Avoid placing any structure on the water course, the margin, the riverbank or in the torrent (*debris dams*, breakwaters or large logs placed artificially).[66]

☞ **BEST.** Conserve all the dead wood in the riparian habitats. Remove it only from the sections where it can get stuck on anthropic elements such as bridges, fords and dams. If possible, do this without using heavy machinery and leave it in natural spaces in the riparian forest, at a distance from the river current.[108]

Giant cane (*Arundo donax*), an exotic, invasive species, propagates fires through riparian habitats. If there are areas of burned cane, the presence of forestry workers and salvage machinery can be used to advantage to control this species.[165]

☞ **AVOID.** Avoid planting exotic and foreign species to stabilise the margins of the riverbank. Prioritise native species.[165]

Do not circulate with machinery on the water course, the margin, the riverbank or in the torrent outside the roads.[66]

FORESTS (NOT RIPARIAN OR FORESTED AREAS ADJACENT TO TORRENTS)

Ensure that the vegetation on the clearing roads and in the corridors and the skidding channels regenerates at the same pace as the harvested area, and avoid creating new roads.[66]

Ensure that the forest roads have adequate sediment sinks.[66]

For specific technical instruction, see *Managing and recovering riverbank vegetation – Technical guide for interventions on riverbanks* [61] and *Methodological guide to good practices in flood management - Manual for managers.*

7.1 l Silvopasteral benefits

Grazing alters ecosystem processes, reducing grass and leaf litter cover, disturbing and compacting the soil, reducing infiltration capacity and increasing soil erosion.[10] For these reasons, the pastures in and adjacent to the burned zones should be fenced in:

☞ **BEST.** Fence the pastures in the burned areas and in the areas between the burned area and water courses, even when the fire did not burn intensely in the latter, to protect the ecosystem, which will slow down the arrival of sediments and runoff in the aquatic environment.

☞ **MEDIUM.** Fence the pastures in the burned areas, but allow moderate grazing in the areas between the burned area and water courses.

☞ **WORST.** Allow grazing in the burned area.

See file “1. Plant cover regeneration”, for the recommended periods for fencing pastures

7. PRESERVATION OF THE QUALITY OF RIVER AND RIVERBANK HABITATS

7.2 Erosion control procedures

7.2 a Whole-tree harvesting

As burned areas that have been timber harvested are more prone to erosion, in the areas sensitive to erosion and without riparian vegetation, or where the riverbank has been so severely burned that it cannot fulfil its function of filtering and retaining sediments, some of the pine logs can be used to construct log debris dams and log erosion barriers. In this case, leave the cut and previously debranched trees to build these control measures, and leave the branches themselves on the logging strip.

7.2 b Stem-only harvesting/ wood-chopping

As burned areas that have been timber harvested are more prone to erosion, in the areas sensitive to erosion and without riparian vegetation, or where the riverbank has been so severely burned that it cannot fulfil its function of filtering and retaining sediments, some of the pine logs can be used to construct log debris dams and log erosion barriers. In this case, leave the cut and previously debranched trees to build these control measures.

7.2 c No harvesting

In the areas that have not been timber harvested, no log debris dams or log erosion barriers need to be installed as the regeneration of plant cover is faster there and the fact that there has been no machinery or clearing decreases the risk of erosion. Sediment polls could be built if infrastructures downriver must be protected.

7.2 d Optimum time for logging

These control measures must be installed as soon as possible after fire because it is during the first rainfall when most erosion happens.[49]

7.2 e Location of logging sites

The control measures must be applied in the areas that are most at risk of erosion. Evaluate the erosion risk as quickly as possible after the fire, according to TABLE 3, or use the method described in *Mapping erosion risk and selecting sites for simple erosion control measures after a forest fire in Mediterranean France* [48] or in the *Guide to managing burned hills. Protocol of actions to regenerate burned areas at risk of desertification* [1].

Furthermore, special attention must be paid to installing barriers on the spots most susceptible to erosion: discontinuities where runoff can accumulate, areas with signs of erosion and problematic areas associated with forest roads.[1]

7.2 f Logging intensity

The less intense the salvage logging operation is, the less erosion control measures are required.

7.2 g Clearing

No information.

7.2 h Site preparation

If the aim is to install erosion control measures, the site must not be prepared beforehand as this is one of the main sources of erosion in post-fire situations.[144]

7.2 i Climate conditions

Log erosion barriers are efficient at capturing sediments in periods when rainfall is light to moderate, but they are not when rainfall is intense or torrential.[49]

7.2 j Sloping land

Log erosion barriers are efficient at capturing sediment on steep slopes (35-55%) but not on slight slopes (10-20%) or moderate slopes (20-35%).[49]

A density of 40 to 50 log erosion measures/ha and 300 m linear/ha is recommended. This way, the course of the runoff is interrupted before the 25 m point and the maximum runoff route is limited to 40 m in 70% of cases.[1]

7.2 k Specific tasks

For more detailed instructions on constructing erosion control measures in the Mediterranean context, see the study *Evaluation of the efficiency of some sediment trapping methods after a Mediterranean forest fire*.[49]

7.2 l Silvopasteral benefits

No information.

GLOSSARY

Area for the Promotion of Forest Management: sites where control of the fuel load must be prioritised to limit the potential for a large forest fire. These strategic actions are not directly related to extinction manoeuvres, but they can intervene in the fire's maximum capacity to propagate, indirectly creating a larger window of opportunity for control. Thus, within a forested plot, a series of sites can be identified that are of huge interest for fire management, whether or not they are included in the specific planning to combat fires.

Enrichment planting: increasing the percentage of desired species or genotypes in a forest, or the biodiversity, through alternating species.

Enriquiment Fraction of canopy cover: vertical projection above the soil of the crown of a plant species, a group of species or a plant stratum; usually expressed as a percentage.

Hydrophobe: aversion to water in soils, which reduces the infiltration rates of the water accumulated on the surface during periods that can vary from a few seconds to hours, days or weeks.

Living stump: a sprout, usually in the form of a bud, which grows out of the main stem of some plants and can be used for its propagation.

Logging strip: area of a forested site where some or all the trees have been recently cut. The logging strip does not include the burned areas where the trees are left standing in clumps.

Ploughing: destruction of vegetation, spontaneous or otherwise to prepare uncultivated land for crops.

Pole stage: development stage, from when natural thinning begins until a girth of 20 cm is achieved.

Prescribed or controlled burn: A controlled or prescribed burn is an intentionally set, completely controlled fire. It also refers to controlled burns to prevent very noxious fires, or controlled burns as a silvicultural practice.

Reshoot: shoot put out later than the first shoots, often after the latter are eliminated through shoot selection. Their number are controlled by means of reshoot selection.

Salvage logging: the harvesting of dead, dying or deteriorating trees (for example because they are decaying or damaged by fire, wind, insects, fungi or other agents), before their timber loses all its economic value.

Sapling stage: development stage comprised of saplings (trees born from a seed, from when the seed shoots until it is 1.30 m in height). The stage ends when there is canopy closure and the trees begin to compete with each other.

Sapling: see pre-thicket

Site quality: relative productive capacity of a specific forested area for the growth of a certain species or a mix of compatible species. It is the outcome of the interaction between climatic, edaphic, physiographic and microbiological factors. Defined as the degree of fertility of a site for tree development; the maximum timber crop an area can sustain in the form of standing trees.

Thicket stage: development stage, from when there is canopy closure until natural thinning begins. Competition intensifies and the mass has an impenetrable appearance.

Timber stage: development stage comprised of trees with a girth of between 20 and 35 cm.

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